第4章　環境社会配慮関連調査

4－1　環境関連法制度

4－1－1　EIA制度の概要

グレナダ国のEIA制度は、2002年に制定されたPhysical Planning and Development Control Act No.25、および2001年に制定されたWaste Management Act No 16 に規定されている（表4-1）。これらの中で、EIAはPlanning and Development Authority (PDA)と大臣（Minister）が管轄するものと規定されている。大臣はEIAにかかる法規を整備し、PDAはその他のEIAにかかる審査、承認、管理等を行う。またActを補完修正するかたちでPhysical Planning and Development Control Bill, 2015が準備されている（2016年6月時点でドラフト）。

表 4-1　EIA関連法規

No.	Legislation	Description
1	Physical Planning and Development Control Act No. 25 of 2002	To make provision for the control of physical development, require the preparation of physical plans for Grenada, protect the natural and cultural heritage, and for related matters.
2	Waste Management Act No. 16 of 2001	To provide for the management of waste in conformity with best environmental practices and related matters
3	(Draft) Physical Planning and Development Control Bill, 2015	To make provision for orderly and progressive development of land and to preserve and improve the amenities thereof; for the grant of permission to develop land and for other powers of control over the use of the land; for the regulation of the construction of buildings and other related matters; to confer additional powers in respect of the acquisition and development of land for planning; to protect the natural and cultural heritage, to repeal and replace the Physical Planning and Development Control Act, 2002.

出典: 法規文書

Physical Planning and Development Control Bill, 2015（ドラフト）の中で、EIAの対象となる開発行為として下表に示す22項目が挙げられている。地熱発電事業（掘削および発電所）は、14番（発電所）、19番（排ガス、廃水、廃棄物、騒音、振動、または放射性物質の発生を伴う開発行為）および22番（湿地、海浜公園、国立公園、保護地域またはその他のセンシティブな環境地域での開発行為）該当するため、EIAの作成が求められる。

表 4-2 EIA 対象となる開発行為

No.	Types of Development
1	Hotels of more than 50 rooms
2	Sub-divisions of more than 10 lots
3	Residential development of more than 25 units
4	Any industrial plant which in the opinion of the Authority is likely to cause significant adverse environmental impact
5	Drilling, quarrying, sand mining and other mining activities
6	Marinas
7	Land reclamation, dredging and filling of ponds
8	Airports, ports and harbors
9	Dams and reservoirs
10	Hydro-electric projects
11	Desalination plants
12	Water purification plants
13	Sanitary landfill operations, solid waste disposal sites, toxic waste disposal sites and other similar sites
14	A power plant
15	An incinerator, sanitary landfill operation, solid waste disposal site, sludge disposal site or other similar site
16	Gas pipeline installations
17	Wind turbines
18	Communication towers
19	Any development projects generating or potentially generating emissions, aqueous effluent, solid waste, noise, vibration or radioactive discharges
20	Any development involving the storage and use of hazardous materials
21	Any coastal zone development
22	Any development in wetlands, marine parks, national parks, conservation areas, environmental protection areas or other sensitive environmental areas.

出典: (Draft) Physical Planning and Development Control Bill, 2015

4－1－2 EIA の TOR (Terms of Reference)

EIA 報告書には、以下の 10 個の項目が網羅されている必要がある。

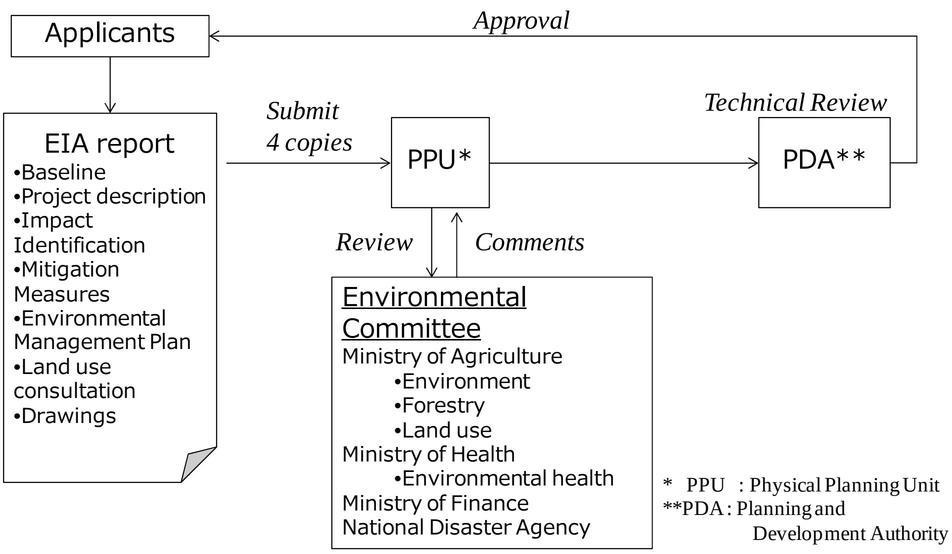
表 4-3　EIA の TOR

No.	Terms of Reference
1	The background to and the objectives of the Project.
2	Specification of the binaries of the EIA Study Area.
3	A description of the Project from inception to operational phases.
4	A description of the physical, chemical, biological, socio-economic and cultural characteristics of the existing environment of the study area.
5	Legislative and Regulatory Requirements
6	Description and quantification of potential environmental effects of the project
7	Assessment of alternatives
8	Mitigation Plan
9	Management and Monitoring Plan
10	A list of References, data sources etc.

出典: Physical Planning Unit提供資料

4－1－3　EIA の手順

EIA 報告書の準備、および審査は下図に示すプロセスで実施される。EIA は Physical Planning Unit に提出し、通常のケースで承認まで約 6 週間かかる。



出典：JICA調査団

図 4-1　EIA 手順の概要

4－1－4　環境関連法規

グレナダ国では 1940 年代より環境関連の法規制が進んでいる。下表に開発行為の際に配慮すべき主な環境関連法規を挙げる。

表 4-4　環境関連法規

No.	Legislation	Description
1	The Beach Protection Amendment Act of 2009	To prohibit sand mining in Grenada
2	Litter Abatement Act of 1973	It has been supplemented by the passage of the waste management Act of 2001, addressing pollution control and abatement of litter
3	Solid waste management act No 11 of 1995	It has established the Solid Waste Management Authority, charged with the duty of developing the solid waste management facilities, and improving the coverage and effectiveness of solid waste storage, collection and disposal facilities of Grenada
4	National parks and Protected Areas Act of1991	To designate and maintenance of National Parks and protected areas.
5	Environmental Levy Act No 5 of 1997	To impose and collect Environmental Levy on certain goods and services
6	Fisheries Act of 1986	To provide for the protection of the marine resources in Grenada, amended in 1999
7	Forest, soil and water conservation act, 1949	To make provision for the conservation of the forest, soil, water and other natural resources of Grenada, amended in 1984

出典: 法規文書を元に調査団作成

4－2　環境関連組織

4－2－1　環境関連組織

環境管理に関わるグレナダ国の政府組織は、主に以下に示すとおり 5 つの省（Ministry）と 3 つの行政局（Authority）である。

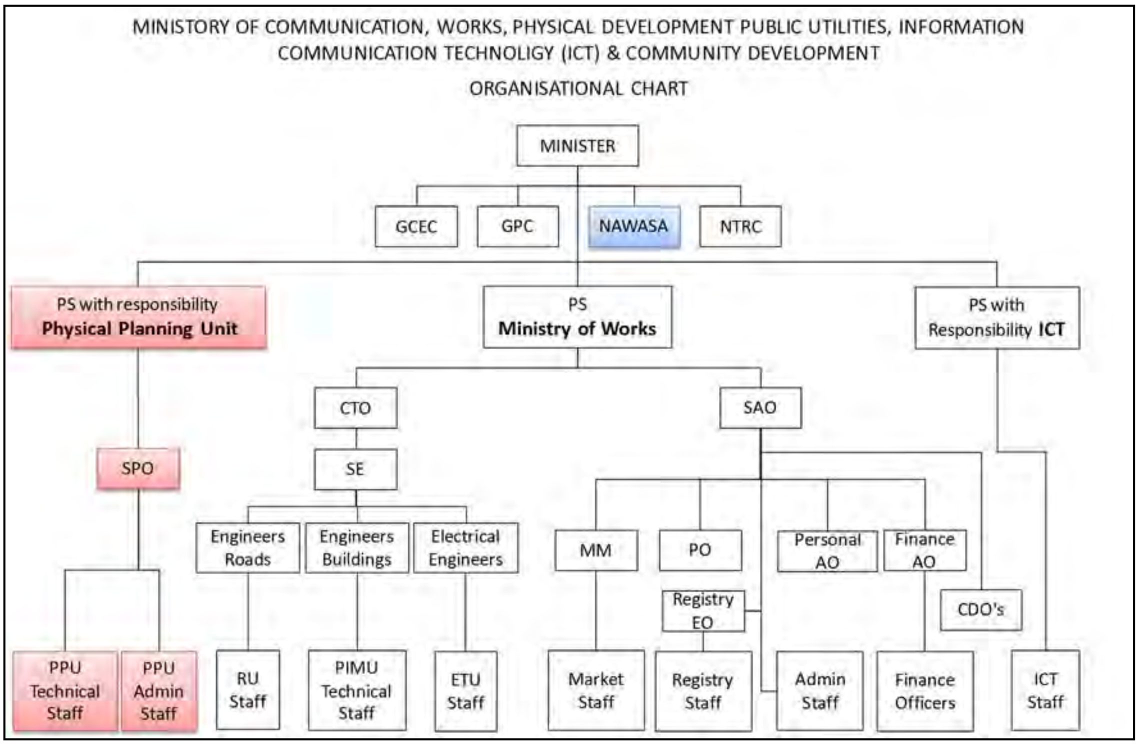
表 4-5　環境関連の行政組織

No.	Institutions
1	Physical Planning Unit, Ministry of Ministry of Communication, Works and Physical Planning
2	The Ministry of Communication, Works and Physical Planning
3	Forestry Department, Ministry of Agriculture Forestry and Fisheries, Public Utilities, Marketing Board and Energy
4	Land Use Department, Ministry of Agriculture, Forestry, Fisheries, and Marketing Board
5	Environmental Health Department, Ministry of Health and the Environment
6	Physical Planning and Development Control Authority
7	Solid Waste Management Authority
8	National Water and Sewage Authority (NAWASA)

出典: グレナダ国政府, 2010

4－2－2　開発局（Physical Planning Unit）

グレナダ国で EIA を管轄する開発局（Physical Planning Unit）の組織図を示す（図 4-2）。開発局は 2015 年現在、Ministry of Communication, Works, Physical Development, Public Utilities, ICT & Community Development 内にある。また、グレナダ国の水資源を管理する NAWASA（National Water and Sewage Authority）も同じ政府組織内に配置されている。



PS: Permanent Secretary, CTO: Chief Technical Officer, SE: Senior Engineer,
SAO: Senior Administrative Office, SPO: Senior Planning Office

出典: Physical Planning Unit 提供資料

図 4-2　組織図

4－2－3　Planning and Development Authority（PDA）

法令 No.25 で組織される EIA 審査機関である PDA の構成メンバーは以下に示す通りである。

(a) A Chairperson (who may be a public officer) appointed by the Minister;
(b) An executive secretary (who may be a public officer) appointed by the Minister;
(c) 3 other members appointed by the Minister from the private sector;
(d) The following public officers as ex officio members-
    (i) The head of the Physical Planning Unit;
    (ii) The Environmental Protection Officer;
    (iii) The Director of Housing;
(e) 2 senior public officers dealing with the following matters and nominated by the respective Ministers-

(i) Agriculture;
(ii) Public works,

As ex officio members;

(f) The manager of the National Water and Sewerage Authority as an ex officio member.

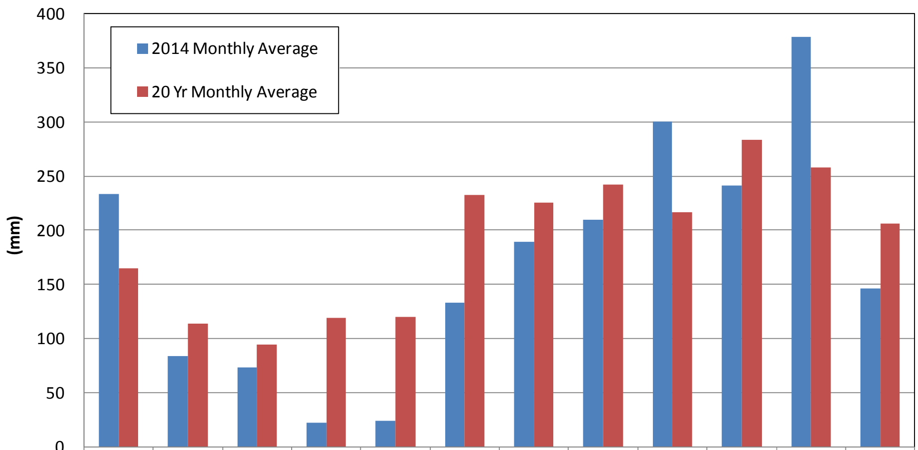
4－3　環境社会配慮関連調査

本項では、地熱開発ポテンシャルが高いとされる St. Catherine 火山周辺を中心に自然環境、ならびに社会環境に関する現状を主に既存資料を用いて分析し、今後の掘削調査において配慮すべき項目について考察する。

4－3－1　環境社会面における現状分析

(1)　気象・水文環境

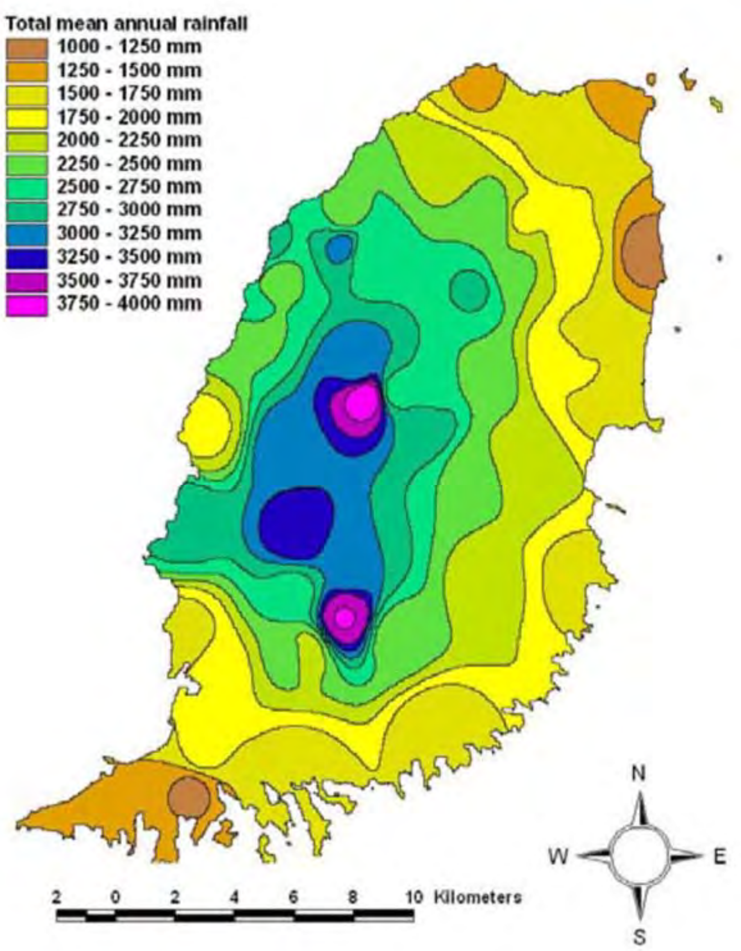
グレナダは湿潤熱帯地域に位置し、貿易風の季節変動の影響を受けて、雨期(6 月から 12 月)と乾季（1 月から 5 月）に分けられる。年間平均降水量は約 2,000mm である（図 4-3）。ただし、地域による降水量の変動が大きく、海岸部で 1,000-1,500mm、山岳部では 4,000mm と幅がある（図 4-4）。海岸部の年平均気温は 28.3～33.3 ℃であり、山岳部の冬季は 20℃程度となる。



	January	February	March	April	May	June	July	August	September	October	November	December
2014 Monthly Average	233.68	84.07	73.66	22.35	24.13	132.84	189.23	209.80	300.23	241.55	378.71	146.05
20 Yr Monthly Average	165.10	113.54	94.23	119.38	120.14	232.16	225.30	241.81	216.66	283.21	258.32	206.50

出典: Ministry of Agriculture, Land use Division

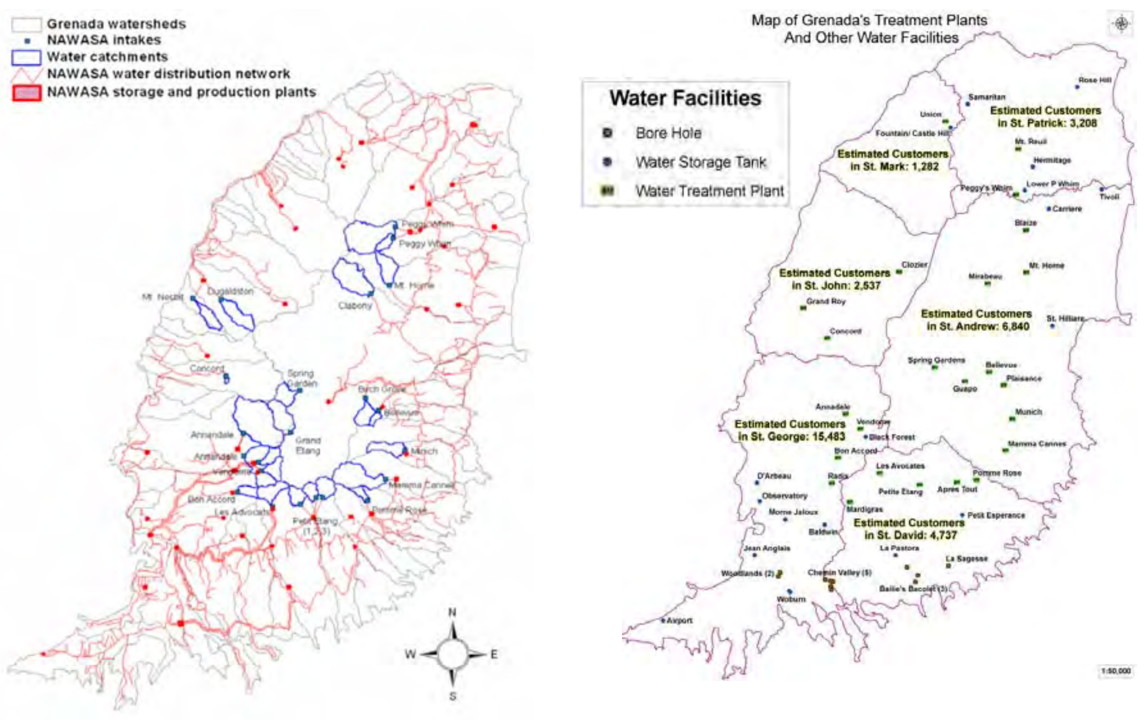
図 4-3　月降水量（2014 年）



出典: IWRM Planning Road Map, 2007

図 4-4　年平均降水量

グレナダは71の流域に分かれている（図4-5）。グレナダには11本の水井戸、17箇所の貯水タンク、および24箇所の水浄化設備があり、雨季には54,600 m^3/day、乾季でも最大31,800 m^3/dayを供給している（IWRM Planning Road Map, 2007）。これらの水資源管理はNAWASAが行っている。



出典: NAWASA提供資料

図 4-5　流域と給水施設位置図

(2)　自然・文化遺産[2]

グレナダには現在 7 箇所の保護区が設定されている。

(1) Grand Etang Forest Reserve
(2) Annandale Forest Reserve
(3) High North Forest Reserve
(4) Perseverance Protected Area
(5) Woburn/Clarks Court Bay Marine Protected Area
(6) Moliniere/Beausejour Marine Protected Area
(7) Unspecified Crown lands at Pearls are designated as a protected area

グレナダ国内の保護地域については、2009 年に東カリブ諸国連合により“東カリブ諸国における保護地域のシステム計画（Systems Plans for the Protected Areas in the OECS）” が策定されている。この中で現況の保護地域ならびに自然・社会遺産の調査を行い、今後グレナダ政府が保護地域として管理するべき地域の選定と提案を行っている。

[2] OECS Protected Areas and Associated Livelihoods (OPAAL), Grenada Protected Area System Plan, 2009（世界銀行とフランス開発銀行の出資による GEF (Global Environmental Facility)の支援により実施された。）

グレナダ国の現在指定されている上述の 7 箇所の保護地域、ならびにシステム計画で新たに提案された保護地域を図4-6に示す。この中で保護地域は以下の4つのカテゴリーに分類、色分けされている。

ここで St. Catherine 火山周辺は緊急指定地域（Immediate Designation）の保護森林（Forest Reserve）、あるいは地域計画エリア（Local Area Planning）に選定されており、グレナダ政府により指定に向けた準備が進められている。

この提案されている St. Catherine 火山周辺の保護指定予定地域の範囲と、本地熱開発予定地との位置関係は、前述（3.3.2 を参照）のとおりである。

表 4-6　保護地域の種類

カテゴリー	属性	代表地域	指定の種類
指定保護地域 Designated Protected Area	すでに政府により保護指定を受けている 7 地域	Grand Etang	Forest Reserve
地域計画エリア Local Area Planning	PPU の地域計画の中で適切に管理される 14 地域	Mt. St. Catherine Addition	Mt. St. Catherine Forest Reserve Addition
優先地域 Priority Area of Interest	調査がされたが、住民生活・観光・開発のために影響が懸念されている 8 地域	South Carriacou Islands	Marine Protected Area
緊急指定地域 Immediate Designation	過去に環境管理計画が策定され調査が実施された地域で、希少種や生態系が存在し至急保護するべき 16 地域	Mount Hartman	National Park
		Mt. St. Catherine	Forest Reserve

出典: OPAAL, 2009

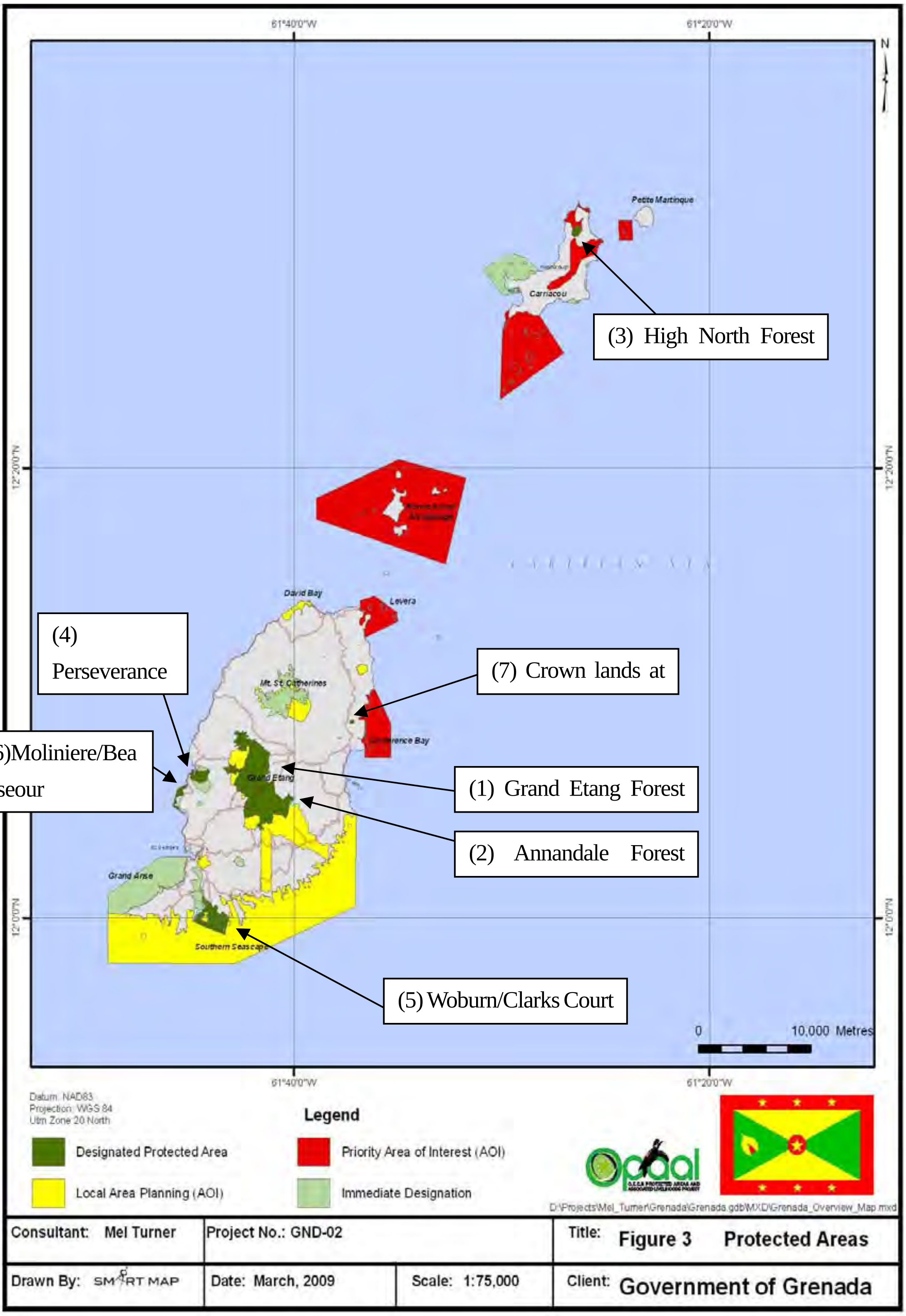


図 4-6　保護地域（既往・提案）

(3) 植物相[3]

グレナダの森林を構成する植生に関する詳細な情報は、一部の草本類を除いてなされていない。そのため希少種や絶滅危惧種に関する情報もまとめられていないが、以下の 3 種類の絶滅危惧種の存在が知られている。

- the Grand Etang Fern (*Danaea sp.*);
- the Cabbage Palm (*Oxeodoxa oleracea*);
- endemic tree species (*Maythenus grenadensis*).

(4) 動物相

グレナダの動物相に関しても、その種類、棲息域ならびに現在の状況を示すデータはほとんど存在していない。その中でも Groome (1970)では、4 種の両生類、8 種のトカゲ、5 種のヘビ、150 種の鳥（このうち 18 種が絶滅危惧）、4 種の固有種の陸生哺乳類と 11 種の固有種であるコウモリが存在するとされている。現在、グレナダで希少種として知られているグレナダハト (Grenada Dove) はグレナダ島南部の Hartman 山周辺に生息すると言われている。

主な希少種を以下に示す。

Endemic sp

- the Cabbage Palm (*Oxeodoxa oleracea*);
- endemic tree species (*Maythenus grenadensis*).
- the Grenada Dove (*Leptotila wellsi*)
- the Grenada Hook-billed Kite (*Chondrohierax uncinatusmurus*)
- the Grenada flycatcher (*Myiarchus nugator*)
- the Scaly-breasted thrasher (*Margarops fuscus*)
- the Lesser Antillian bullfinch (*Loxigilla noctis*)
- the Lesser Antillian tanager (*Tangara cucullata*).

なお、以下はヨーロッパ入植後から現在までにすでに絶滅してしまった動物種である(CCA/GOG/USAID, 1991)。

- the Manatee (Trichecusmanatus)
- the Grenada parrot (*Amazona sp.*)
- the Agouti (Dasyprocta albida)
- Neuweid's Moon Snake (*Pseudoboaneuweidi*)
- Shaw's Racer (Liophis melanotus)
- the Morocoy Tortoise (*Geochelone carbonaria*)

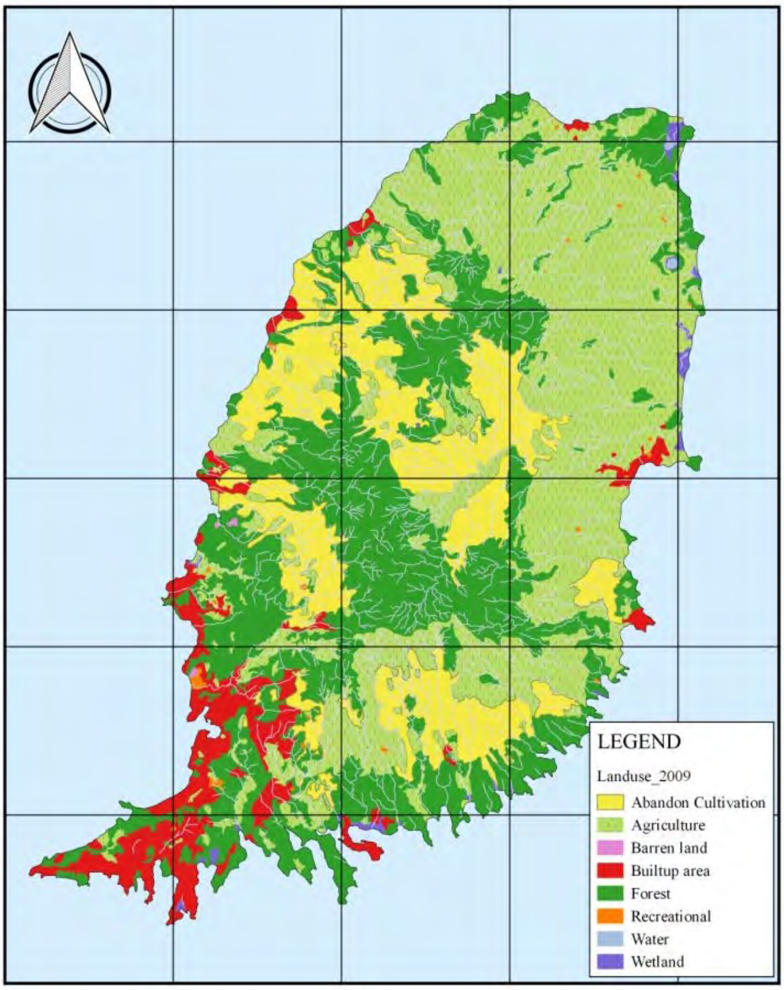
[3] The Convention on Biological Diversity in Grenada, Biodiversity Strategy & Action Plan, 2011

(5)　土地利用

グレナダの土地利用状況を図 4-7 に示す。グレナダ島南西部および、島の周囲の主要開発地を除き、ほとんどが農地または耕作放棄地、および山岳地域の森林地帯である。

農作物の代表的なものは、カカオ、ナツメグ、バナナ、さとうきび、果実等である。

地熱開発の候補地である St. Catherine 火山周辺も大部分が農地として利用されている私有地が広がる。



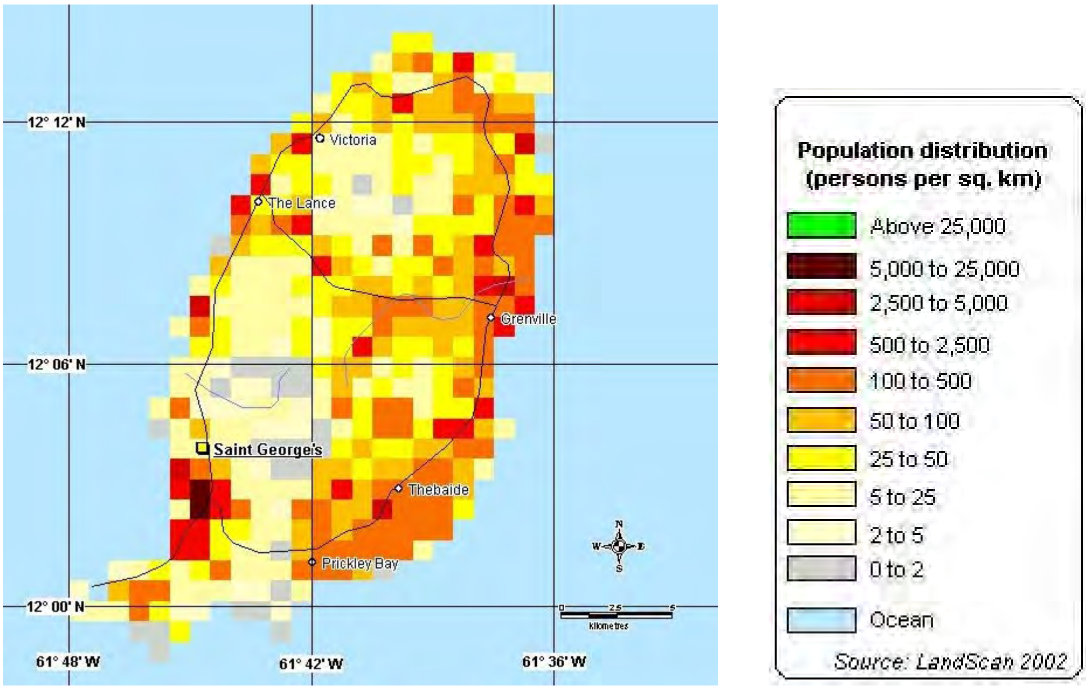
出典: Ministry of Agriculture提供資料

図 4-7　土地利用の状況

(6)　住民の生活区域

グレナダ国の人口は約 10 万人である。居住区は主に首都セントジョージズのある南西地域（5,000~25,000 人/ km²）、および島の周囲ならびに東西を横断する幹線道路沿いの主要な町および集落（500~5,000 人/ km²）である（図 4-8）。

St. Catherine 火山周辺の地熱開発候補地あるいはアクセス地については、数は多くはないが住民の居住地域に該当する可能性がある。



出典: UNOSAT

図 4-8　人口分布

4－3－2　環境社会配慮項目の洗い出し

本プロジェクトに対する環境社会配慮項目を洗い出すために、表 4-7 に示すとおり予備的スコーピングを実施した。環境社会影響の分析を行った項目は、「国際協力機構環境社会配慮ガイドライン」（JICA、2010 年 4 月）に示されるチェック項目を参照して選定した。影響は、準備段階(試掘、用地取得)、建設段階（施設の建設）、供用段階（施設の稼働）について、回避・緩和策を講じなかった場合を想定してその程度を評価した。

表 4-7　予備的スコーピングの結果

分類	No	影響項目	評価			評価理由
			準備段階	建設段階	供用段階	
汚染対策	1	大気質	B-	B-	B-	**準備・工事**：噴気試験に伴い、硫化水素(H_2S)を含むガスの発生の可能性がある。また、杭井掘削や施設建設に伴う建設機材の稼動に伴い、排気ガスの発生が想定される **供用**：硫化水素(H_2S)が蒸気とともに排出されることが想定される
	2	水質	B-	B-	B-	**準備・工事**：抗井掘削や施設建設時に伴う泥水の発生が想定される **供用**：施設から汚水・排水が排出されることが想定される
	3	廃棄物	B-	B-	B-	**準備・工事**：抗井掘削や施設建設時に伴う掘削汚泥、建設残土や廃材の発生が想定される **供用**：施設から廃棄物（汚泥、廃油など）の発生が想定される
	4	土壌汚染	D	D	D	土壌汚染を引き起こすような作業などは予定されない
	5	騒音・振動	B-	B-	B-	**準備・工事**：抗井掘削による地熱流体の噴出や、建設機材の稼動などによる騒音の発生が想定される **供用**： 施設（発電機、蒸気タービン、冷却塔など）の稼働による騒音の発生が想定される
	6	地盤沈下	D	D	C	**準備・工事**：抗井掘削や施設建設時の地熱流体の採取は限定的である **供用**：地熱流体の採取により抗井周辺で地盤沈下の可能性があるが、詳細な調査が必要である
	7	悪臭	B-	B-	B-	硫化水素が発生した際に悪臭の発生が想定される
	8	底質	D	D	D	底質へ影響を及ぼすような作業などは予定されない
自然環境	9	保護区	A-	A-	A-	プロジェクト予定地は、Mt.St.Catherine Forest Reserve 近傍に位置する
	10	生態系/生物相	A-	A-	A-	土地の改変や施設の稼働・存在などにより、地域の生態系および生物相に影響を及ぼすことが想定される
	11	水象	B+	B+	D	**準備・工事**：掘削時に河川水ないし地下水を用水として用いるため流量の低下が想定される **供用**：河川水ないし地下水を用水として用いるが、その量は小さい
	12	地形・地質	D	B-	D	**準備**：大規模な抗井掘削は予定されないため影響は小さい **工事**：施設（発電所建屋、蒸気および熱水輸送管、冷却塔など）の建設工事により地形の改変が想定される **供用**：地形・地質に影響を及ぼす可能性のある行為は予定されない

分類	No	影響項目	評価			評価理由
			準備段階	建設段階	供用段階	
社会環境	13	住民移転	C	C	C	プロジェクト予定地の用地取得は必要となるものの、予定地に居住する住民は少数であると想定されるが掘削計画策定後に調査が必要
	14	貧困層	D	B+	B+	**準備**：試掘による雇用機会の創出は限定的である **工事・供用**：施設の建設や稼働により、雇用機会の創出など地域経済への正の影響が想定される
	15	少数民族・先住民族	D	D	D	プロジェクト予定地およびその周辺に、特段の配慮が必要な少数民族・先住民族はいない
	16	雇用や生計手段等の地域経済	D	B+	B+	**準備**：試掘による雇用機会の創出は限定的である **工事・供用**：施設の建設や稼働により、雇用機会の創出など地域経済への正の影響が想定される
	17	土地利用や地域資源利用	D	D	B+	**準備・工事**：土地利用や地域資源利用などへの影響はほとんどない **供用**：地熱水の発電以外の利用が可能となる
	18	水利用	A-	A-	D	**準備・工事**：掘削水には河川水ないし地下水を用水として用いるため水道水源への影響が想定される **供用**：河川水ないし地下水を用水として用いるが、その量は小さい
	19	既存の社会インフラや社会サービス	D	D	D	周辺地域に影響を受けやすい施設(住居、学校、医療施設など)はない
	20	社会関係資本や地域の意思決定機関等の社会組織	D	D	D	社会関係資本や地域の意思決定機関などへの影響はほとんどない
	21	被害と便益の偏在	D	D	D	周辺地域に不公平な被害と便益をもたらすことはほとんどない
	22	地域内の利害対立	D	D	D	地域内の利害対立を引き起こすことはない
	23	文化遺産	C	C	C	プロジェクト予定地に文化遺産等は存在しないと考えられるが、確認調査が必要である
	24	景観	D	D	A+/-	**準備・工事**：大規模な工事は想定されないため、影響は一時的で小さい **供用**：施設（発電所建屋、蒸気および熱水輸送管、冷却塔など）の存在により、景観への影響が想定される
	25	ジェンダー	D	D	D	ジェンダーへの特段の影響は想定されない。
	26	子どもの権利	D	D	D	子どもの権利への特段の影響は想定されない。
	27	HIV/AIDS 等の感染症	B-	B-	D	**準備・工事**：大規模な工事は想定されないが、作業員の流入により感染症が広がる可能性が考えられる **供用**：施設の労働者数は限られ、影響は小さい

分類	No	影響項目	評価			評価理由
			準備段階	建設段階	供用段階	
	28	労働環境(労働安全を含む)	B-	B-	B-	標高が高い地域なため、作業員の労働環境に配慮が必要である
その他	29	事故	B-	B-	B-	試掘、建設工事、施設の稼働に事故に対する配慮が、それぞれ必要である
	30	気候変動	D	D	A+	**準備・工事 :** 大規模な工事は想定されないため、影響は一時的で小さい **供用 :** 本プロジェクトは温室効果ガスの削減に寄与する

A+/-: 比較的大きな正・負の影響が想定される。

B+/-: ある程度の正・負の影響が想定される。

C+/-: 影響の程度は不明である（更なる調査が必要であり、影響は調査の進捗とともに明らかになる)。

D: 影響は想定されない。

出典 : JICA調査団

予備的スコーピングの結果、大気質、水質、廃棄物、騒音、保護区、生態系/生物相、水象、地形・地質、景観について影響が生じることが想定された。また、貧困層、雇用や生計手段等の地域経済、土地利用や地域資源利用、水利用、HIV/AIDS 等の感染症、労働環境、事故、気候変動についても正ないし負の影響が想定されるが、住民移転、地盤沈下および文化遺産に関しては、試掘計画が策定されたのち、詳細な調査が必要であるとされた。

4－3－3　試掘候補地の周辺環境

本調査で選定された 3 箇所の試掘候補地の周辺状況は、3-3-6 章に詳しく述べられている。選定した C,D,F いずれのサイトも民間の土地であり、農地として利用されている。掘削工事を実施するにあたっては土地収用が必要となる。ただし掘削敷地ならびにアクセス道路周辺に住居はなく、住民移転は発生しないと想定される。

4－3－4　JICA ガイドラインとの整合性

地熱発電 ESIA の手続きについては現行のグレナダ国内の法令ならびに規則により以下の通り整理される。

表 4-8　グレナダの法制度における ESIA 手続きのまとめ

Item	Content	Regulation
Project subject to ESIA	Defined	Bill
Timing for Execution	4 months	Not regulated
Content	TOR is prepared	PPU
Public Consultation	Needed	Act
Review Committee and Approval Authority	PPU	Act
Time Limit of Review	Up to six weeks	Not regulated
Disclosure of Information	-	Not regulated

出典：JICA調査団

なお、現行のグレナダの規定において、環境配慮に関しては JICA ガイドラインの要求事項をおおよそ網羅しているものの、社会配慮に関する規定が十分ではなく、JICA ガイドラインまたは国際標準の要求を満たすために、以下に示す項目を追加することを提案する。

- ゼロオプションを含む代替案の比較検討
- 用地取得・住民移転
- 住民協議

また、社会配慮項目における JICA ガイドラインとの相違点とその緩和策の提案を下表にまとめる。

表 4-9　社会配慮項目における JICA ガイドラインとの相違点

Issues	JICA guideline	Proposed Project Policy
Land compensation	All affected persons should be compensated for land acquisition, regardless of legal status of land use	All affected persons should be compensated regardless of legal status
Compensation for houses and others	All affected structures will be compensated according to replacement cost, regardless of legal status	All affected structures will be compensated according to replacement cost
Compensation Price	Full replacement cost should be provided as much as possible since the official price may not represent a full replacement cost	Full replacement cost at the market value should be provided as much as possible
Compensation for losing income or means of livelihood	All loss of income shall be compensated	All loss of income shall be compensated
Support for livelihood restoration	Support to restore at least the livelihood before the project started	Support to restore at least the livelihood before the project started

出典：JICA調査団

4－3－5　環境関連組織の能力評価

本案件の環境社会配慮に関わる主な組織とその能力についての評価は以下のとおりである。

1）　PPU（Physical Planning Unit）：

EIA の規定整備、審査を管理する組織である。環境に関する専門的判断は他の関係部局

と連携して行っている。

2)　環境関連の政府組織

環境の各分野に関する専門機関として、Ministry of Agriculture 内の Environmnet 部局, Forestry 部局ならびに Land Use 部局がそれぞれ管轄しており、本プロジェクトを推進するにあたりこれらの機関に相談することが十分可能である。その他の機関として、Solid Waste Management Authority、Environmental Health Department, Ministry of Health and the Environmen、Port Authority や Airport Authority も本プロジェクトへの関与にも積極的な姿勢を示している。

3)　エネルギーオフィス（財務・経済開発、エネルギー、貿易および政策支援省エネルギーおよび持続可能開発局）：

本プロジェクトの推進部局であるが、環境管理に関しては専門家がおらず、案件管理のためには関係政府組織との連携のもと実施していく必要がある。

4)　民間ステークホルダー

民間のステークホルダーは本プロジェクトの積極的な関与を希望している。特に環境 NGO 団体に対しては、今後は適切な SEP（Stakeholder Engagement Plan）の策定のもと、早い段階から十分な協議の場を設ける必要がある。

第5章　プレフィージビリティースタディ

5−1　プロジェクトの目的

5−1−1　上位目標（案）

グレナダ国の再生可能エネルギー源の割合を高める。

[参考: グレナダ国国家エネルギー開発計画（The National Energy Policy of Grenada – A Low Carbon Development Strategy For Grenada, Carriacou and Petite Martinique, November 2011）(抜粋)]

Renewable Energy Goal: 20% of all domestic energy usage (electricity & transport) will originate from renewable energy sources by 2020.　2020年までに、家庭用エネルギー（電気、交通）の20%を再生可能エネルギー源とする。

Power Sector Goal: Transition to an efficient, low-carbon, national electricity generation and interconnection network that ensures safe, efficient, affordable and environmentally friendly energy services　効率的で安全、廉価かつ環境親和型のエネルギーサービスを確実にする効率的で低炭素型の発電と相互接続網への移送

5−1−2　プロジェクト目標（案）

グレナダ国グレナダ島において地熱発電所を建設する。

5−2　プロジェクトの計画概要

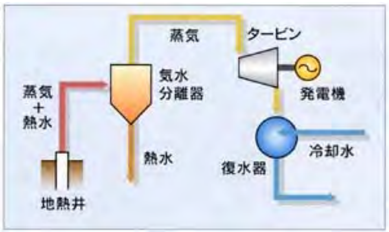
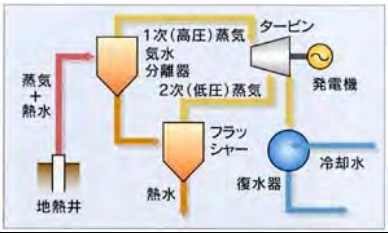
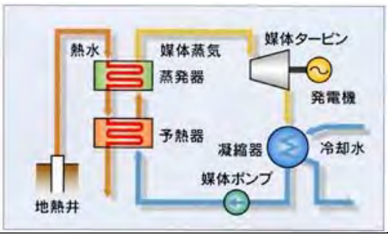
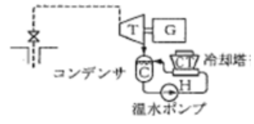
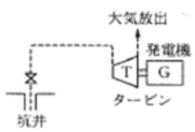
5−2−1　地熱発電所

(1)　地熱発電形式

地熱発電形式には、地熱エネルギーを電気エネルギーに変換する方法によって、シングルフラッシュ方式、ダブルフラッシュ方式、バイナリー方式、複合方式等が普及している（表5-1）。

本事業では、地熱資源のエンタルピーを考慮して、構造がシンプルで世界的に最も普及している復水式フラッシュサイクル方式とする。

表 5-1　地熱発電の方式

地熱発電方式		発電方法と特徴
シングルフラッシュ 		生産井にて回収される二相流体を、気水分離器を用いて蒸気と熱水に分離して、その蒸気で直接タービンを駆動させ発電する方式をフラッシュ方式という。 「シングルフラッシュ方式」は一基の気水分離器を用いる最も一般的な方式である。
ダブルフラッシュ 		フラッシュ方式のひとつ。 気水分離器で分離後の熱水が高エンタルピーの場合には、その熱水をフラッシャーに導入し減圧することで更に蒸気と熱水に分離することが出来る。「ダブルフラッシュ方式」はこの蒸気も使用する方式である。シングルフラッシュ方式の 10～20%程度の出力増加が期待される。
バイナリー式 		地熱流体から沸点の低い媒体（フロン類、炭化水素系流体等）へ熱交換することで得られる気体を用いて発電する方式である。地熱流体のエンタルピーが低く、熱水の割合が高い場合に利用されることが多い。フラッシュ方式に比べ発電容量は小さい。
複合方式		フラッシュ方式とバイナリー方式を組み合わせた方式。
プラントの種類	復水式 	高い発電効率を得るためにタービンから排出される蒸気を復水器で強制的に凝縮させる方式
	背圧式 	タービンから排出される蒸気を大気へそのまま放出する方式。

出典：資源エネルギー庁ホームページ、および地熱発電必携を参考にJICA調査団作成

(2)　　設備容量

GRENLEC への聞き取り調査によれば、グレナダのベースロードは 18 MW 程度である。また、Jacobs (2016)によると、開発対象地域における地熱資源量は、20 – 90 MW と想定されている。従い、グレナダのベースロードを地熱発電で賄うことが可能である。ただし、資源確認のための試掘調査がまだ実施されていないので、現段階では資源量は小さく見積もる必要がある。さらに、ベースロードとはいえ中長期的には増減するのでその一部はミドル電源で対応するのが現実的である。従い、本事業で建設する地熱発電所は 15MW のベースロードを供給する設備を計画する。

(3) タービン・発電器

維持修繕時にも地熱発電を継続するために複数のタービン・発電器のユニットを据え付けるものとする。単機容量は運用予備力（グレナダ国では供給予備力とほぼ等しい）を超えてはならないので単機容量は 5MW 程度が適切である(表 5-2)。所内電力 10%と仮定すると、15MW のベースロードを供給する地熱発電所の設備として単機容量 5.5 MW の機器を 3 ユニット導入するものと計画する。

タービンはシングルフラッシュ復水型とし発電機は空冷の三相同期発電機とする。

発電器は全閉水冷式、出力電圧 11kV、周波数 50 Hz、相数 3 相、回転数 3,000rpm とする。

表 5-2 単機容量検討表

GRENADA

A comparison for Selection of number of turbo-generator units to be installed

Grenada		15 MW x 1 unit	10 MW x 1 unit plus 5 MW x 1 unit	7.5 MW x 2 units	5 MW x 3 units
1.	System reliability when fails Reserve margin > Largest unit capacity on the system (Data: Queen's Park P/S) - Rated installed capacity: 46 MW in 2010 - Capacity to be added: 15 MW - Rated installed capacity considered: 61 MW - Generation capacity*: 37-39 MW (tentative) - Peak demand: 31 MW in 2010 - Reserve margin (RM): 6-8 MW	Not Suitable (RM < 15 MW)	Not Suitable (RM < 10 MW)	Marginal (RM ≈ 7.5 MW)	☑ Suitable (RM > 5 MW)
2	Not greater than a 20% of the peak demand (6 MW) (DOMLEC 2015)	Not Suitable (< 15 MW)	Not Suitable (< 10 MW)	Marginal (≈ 7.5 MW)	☑ Suitable (> 5 MW)
3	Continuous operational ability of the power plant while maintenance, or when sudden shut down.	Not possible	Possible (Continuously deliverable output: 10 MW or 5 MW, variable)	Possible (Continuously deliverable output: 7.5 MW)	☑ Possible (Continuously deliverable output: 10 MW in normal case)
6	Flexibility to fluctuation in power demand due to likely unstable base load conditions	Lowest	Second highest	Second lowest	☑ Highest
7	Initial Cost, (Indicative)	☑ Lowest	Second highest	Second lowest	Highest
8	Maintenance cost	☑ Lowest	Second highest	Second lowest	Highest
9	Hand-ability - Transportation (port and inland) - Installation - Maintenance	Low	Relatively low	Medium	☑ High
10	Spare Parts compatibility between units	-	Not compatible	☑ Compatible	☑ Compatible

Generation capacity= Rated (61 MW) x Average output capacity (0.75)x Availability (0.90) x failure rate (0.90 – 0.95) - *tentative*

出典：JICA調査団

(4)　復水設備

タービンから排出される蒸気を復水器で冷却して凝縮し比容積を減少させる。復水器は直接接触式を採用する。冷却は河川水を貯留する高架冷却水槽から冷却水を復水器に送水することによって行う。

タービンから排出される蒸気には非凝縮性ガスが含まれことを想定する。この非凝縮性ガスは復水器から復水器近傍に設置するガス抽出器に送る。

(5)　その他所内設備

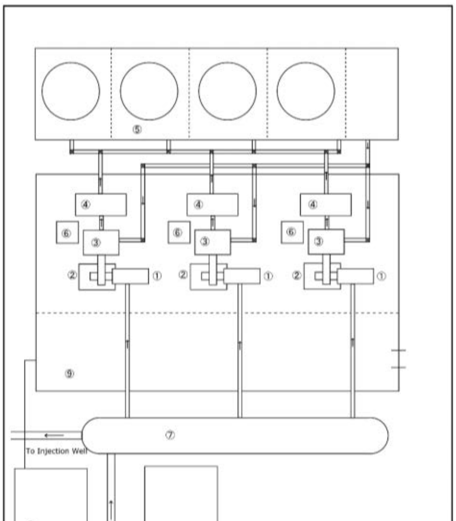
・抽出器・ガス放出

ガス抽出器はハイブリッドタイプを採用する。ガス抽出器で抽出された比凝縮性ガスは、冷却塔へ送り、冷却塔に設置する送風装置によって排出される空気と共に大気へ放出する。

・変圧器

発電機発電端にて電圧 11kV で発電された電気は変圧器で送電電圧へ昇圧される。送電電圧は 33kV を想定する。変圧器はタービン建屋を挟んで冷却塔の反対側へ配置する。これは、冷却塔から排出される非凝縮性ガスや水滴との接触を極力避けるためである。

図 5-1 に想定配置図を示す。

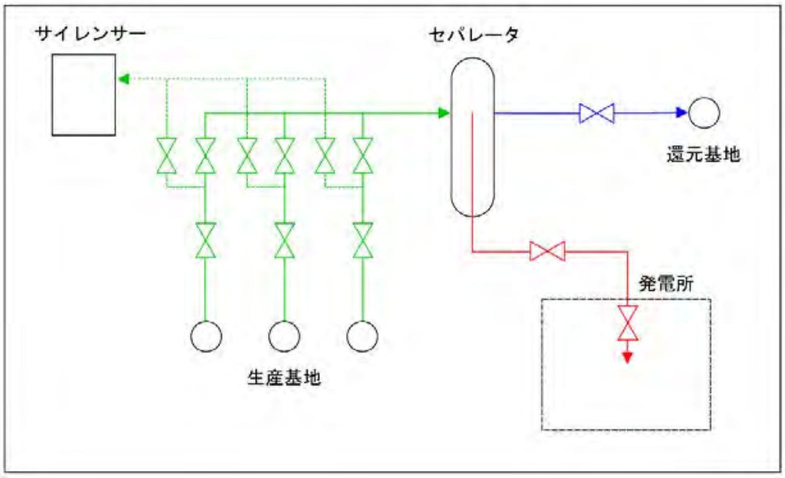


出典：JICA調査団

図 5-1　発電所の配置図例

5－2－2　地熱流体生産・還元システム（FCRS）

本検討では、生産井にて生産される流体は蒸気と熱水の混合流体（二層流）であると想定する。生産された流体は、汽水分離器によって蒸気と熱水に分離する。蒸気は蒸気輸送管により、生産井基地から発電プラントまで輸送する。熱水は熱水輸送管により、還元基地に送る。システムのレイアウトを下記に示す。



出典：JICA調査団

図 5-2　FCRS 概念図

(1)　生産井、還元井

生産井 3 本、還元井 1 本により 15MW の発電所運用を行う。生産・還元井ともに 2,000m 級の坑井を想定し、すべて傾斜掘削とする。掘削サイトは、C、D ないし E サイトと想定する。掘削を計画している 4 評価井と 2 生産井のうち、3 坑井を生産井、 1 坑井を還元井に利用すると仮定する。

(2)　汽水分離器、ロックマフラー、熱水貯留地

- サイクロン型気水分離器を生産井基地に設置し、地熱流体から乾き蒸気を分離する。
- 蒸気または熱水を大気に放出する際に、騒音を低減するように生産井基地にロックマフラーを設置する。
- ロックマフラー等から排出される廃棄水を一時貯留する目的で、熱水貯留地を設置する。一時貯留された廃棄水は、還元井によって地中に還元される。

(3)　蒸気輸送管

グレナダにおける開発候補地は、いずれも山岳地にあり起伏に富む。また、生産・還元井の掘削地域の選定結果次第では蒸気輸送管の延長は変化するが、３掘削基地から平均長を 3 km 程度、合計 9km 程度敷設することとする。主蒸気配管の配管径は 500 mm とする。

5－2－3　電力輸送設備概要

設備容量 15MW の発電所から最大消費地のセントジョージズまでの電力輸送距離は国道に沿って敷設した場合でも 40km 未満である。このため、送電線容量は 33kV が適切である。この地域に敷設されている現況の電力輸送設備は 11kV 以下の低容量なので、地熱発電所用に新設する必要がある。33kV の電力輸送設備は通常地上高 8.5m ～12.5m の電柱架空線が使用される。このため、既存国道沿いに敷設することが適切であると考える。本計画では、図 6-3 に示す Grand Etang Lake を通る既存 11kV の電力輸送ルートを想定し、100%の冗長性をもつ 2 基系統の電力輸送線の敷設を想定する。総延長は 40 km x 2 系統を計画する。

出典：JICA調査団

図 5-3　送電線レイアウト案

5－3　事業費概算

事業費の概算を表 5-3 に示す。

通常、地熱発電開発の事業費には地表調査費地質・地化学調査、物理探査）も含めるが、本件グレナダ国の地熱発電開発事業においては本 JICA 調査及び Jacobs(2016)によりすでに完了しているため、本検討には含めない。ここでは、今後の実施が見込まれる、1) スリムホール掘削、2) 評価井掘削、3) プロダクション井掘削、4) 送電線建設、および 5) 発電所建設について検討した。

検討の結果、概算総工費は約 123 Millwion US$となった（表 5-3）。

表 5-3　事業費概算結果

Cost Items		Cost (US$)
Slimhole Drilling	3 Wells	7,500,000
	Civil Works & Preparation	4,000,000
Appraisal Drilling	4 Wells	20,800,000
	Civil Works & Preparation	9,200,000
Production Drilling	2 Wells & Production Test	12,400,000
	Civil Works & Preparation	3,900,000
Field Development	FCRS Construction	6,000,000
	Civil Works & Preparation	600,000
Construction of Power Plant		35,200,000
Transmission Line (2 lines)		18,000,000
Consultancy Services (DD, SV)		5,800,000
	Total	123,400,000

掘削費用、FCRS 建設費用は過去事例を参考にした。土木工事費は Physical Planning からの情報を参考に積算した。

出典：JICA調査団

各段階における想定は以下のとおりである。

(1)　スリムホール掘削

- 1,500m　級調査井 3 本、掘削は C、D 及び F サイトでの掘削を想定する
- 1 本当たり 2.5　百万 US$
- 掘削準備費用（アクセス道路の整備、用地取得、土地造成工事（各 40m×40m）、掘削用水の確保費用（約 4 百万 US$）を含む）

(2)　評価井掘削

- 2,000m 級、生産井仕様（最終掘削径 8-1/2”）、4 本の掘削。掘削は C、D ないし E サイトで行う。
- 1 本当たり 5.2 百万 US$（坑井試験を含む）
- 掘削準備費用（アクセス道路の整備、用地取得、土地造成工事（各 100m×100m）、掘削用水の確保費用を含む）

(3)　プロダクション井掘削

- 2,000m 級、生産井仕様（最終掘削径 8-1/2”）、2 坑井。掘削は C、D ないし E サイトで行う。
- 1 本当たり 6.2　百万 US$（井戸試験、噴気試験を含む）
- 掘削準備費用（アクセス道路の整備、用地取得、土地造成工事（各 100m×100m）、掘削用水の確保費用を含む）

(4)　流体輸送、還元施設

- 各生産基地でセパレーター、ロックマフラー設置
- 径 500 mm、各掘削基地から約 3km、総計 9km の流体輸送管
- 準備作業（アクセス道路、用地取得、輸送管ルート整備）

(5)　発電所建設

- 単機容量 5MW の地熱蒸気タービン発電器ユニットを 3 ユニットの据え付け
- 復水器、冷却塔、他付帯施設の建設

- 準備作業（アクセス道路、用地取得（100m x 150m）、土地造成など）

(6) 送電線建設

- 33kV の架空輸送設備、2 系統を想定、
- 首都セントジョージズに変電設備に接続するための約 40 km x 2 系統
- 地上高約 10m コンクリート製電柱使用
- 1 km あたり 0.25 百万 US$を想定
- 準備作業（アクセス道路、用地取得その他）

(7) コンサルタントサービス

- 詳細設計、施工監理業務
- （業者等）調達支援業務
- 掘削および発電所建設のための ESIA 実施

(8) その他費用

以上の他、下記のような費用が想定される。

- 関税や消費税等の税金
- 事業推進のために必要な政府職員の雇用
- 政府内手続き等に必要な職員雇用費を除く事業管理理

ただし、事業に係る費用が免税になる可能性があり、また政府が必要とする事業推進経費（管理費）なども、組織運営形態に大きく影響される可能性が高いので、本調査の財務分析には含めないことにする。

5－4 実施体制モデル

地熱開発実施体制について表 5-2 に示す 4 つのモデルを想定した。いずれのモデルにおいても、地上プラント（SGAS、発電所）と送電線の建設事業推進には、民間企業の参入を仮定した。また、試掘（スリムホール）の掘削には、グレナダ政府に対する無償資金支援が投入されることを仮定した。モデル 1,2 では、政府による地熱資源調査段階・項目が多く、民間参入が容易な状況のため、関心表明・入札・評価に係る期間を 1 年とした。一方、モデル 3,4 では、地熱資源に関するデータが少なく民間側の負担額も大きくなるため、関心表明・入札・評価期間を 2 年とした。

表 5-4 事業実施モデルの想定

モデル	政府／民間	作業区分
Model-1	政府	試掘井、資源量評価井掘削、生産井掘削、入札（期間 1 年）
	民間	地上プラント（SGAS、発電所）建設
Model-2	政府	試掘井、資源量評価井掘削、入札（期間 1 年）
	民間	生産井掘削、地上プラント（SGAS、発電所）建設
Model-3	政府	試掘井、入札（期間 2 年）
	民間	資源量評価井掘削、生産井掘削、地上プラント（SGAS、発電所）建設
Model-4	政府	入札（期間 2 年）
	民間	試掘井、資源量評価井掘削、生産井掘削、地上プラント（SGAS、発電所）建設

出典：JICA調査団

モデル 1：政府は、試掘井戸掘削から生産井掘削を行う。ただし、試掘井掘削は無償資金の投入を期待し、その後の生産井仕様の資源量評価井と生産井掘削は譲許的融資を得て行うと仮定する。生産井や還元井として利用可能な坑井は、事業を実施する民間企業に売却する。事業に参画する民間企業は、地上プラント建設と送電線を建設し、地熱発電所と新設送電施設の運営維持管理を行う。

モデル 2：政府は、無償資金による試掘井と譲許的融資による生産井仕様の資源量評価井の掘削を行う。生産井や還元井として利用可能な坑井は、事業を実施する民間企業に売却する。事業に参画する民間企業は、生産井、地上プラント建設および送電線を建設して地熱発電所と新設送電施設の運営維持管理を行う。

モデル 3：政府は、無償資金による試掘井のみの掘削を行う。事業に参画する民間企業は、生産井仕様の資源量評価井掘削、生産井掘削、地上プラントおよび送電線の建設を行って地熱発電所と新設送電施設の運営維持管理を行う。

モデル 4：現在までの地表調査の結果だけで、投資に値するだけの資源が存在すると判断する民間企業が存在する可能性がある。この様な企業は、生産井戸の転用できない試掘（スリムホール）を実施しないで、直接生産井戸仕様の資源量評価井戸を掘削するものと考えられる。モデル 4 はこの様なケースを想定している。ただし、財務分析上は、政府が試掘のみを無償資金で実施するケースのモデル 3 と同一に取り扱うことができる。

5－5 モデル毎の事業費配分

モデル毎に事業費を配分した表を表 5-5 に示す。この表には、無償資金で実施する試掘関連費用が含まれていないので、表 5-3 に示す、総事業費と異なる。また、業者調達にかかる調達期間がことなると設定したモデル 1、2 とモデル 3、4 とでも多少異なっている。後述の財務分析は、このモデルに従って行う。

5−6 モデル毎の事業実施スケジュール

モデル毎の事業実施スケジュールを表 5-6 に示す。このスケジュールは、「最短」を仮定している。現実的には、資金調達の目途や関心を表明する民間企業の有無などで、適宜見直す必要があるが、後述の財務分析はこのスケジュールによって行う。

表 5-5　モデル毎の事業費配分

Model-1		
Organization in Charge	**Cost Items**	**Cost (USD)**
Public Entity (Gov)	Civil Works & Preparation	13,100,000
	Slimhole Drilling (3 Wells)	0
	Appraisal Drilling (4 Wells)	20,800,000
	Production Drilling (2 Wells, Production Test)	12,400,000
	Subtotal	***46,300,000***
	Consultancy Services (DD, SV)	1,850,000
	(ESIA)	0
	(Tender)	500,000
	Subtotal	***2,350,000***
Total		***48,650,000***
Private Entity (Sponsor)	Civil Works & Preparation	600,000
	Field Development	6,000,000
	Construction of Power Plant	35,220,000
	Transmission Line (2 lines)	18,000,000
	Subtotal	***59,820,000***
	Consultancy Services (DD, SV)	2,390,000
	(ESIA)	200,000
	(Tender)	0
	Subtotal	***2,590,000***
Total		***62,410,000***
Grand total		***111,060,000***

Model-2		
Organization in Charge	**Cost Items**	**Cost (USD)**
Public Entity (Gov)	Civil Works & Preparation	9,240,000
	Slimhole Drilling (3 Wells)	0
	Appraisal Drilling (4 Wells)	20,800,000
	Production Drilling (2 Wells, Production Test)	0
	Subtotal	***30,040,000***
	Consultancy Services (DD, SV)	1,200,000
	(ESIA)	0
	(Tender)	500,000
	Subtotal	***1,700,000***
Total		***31,740,000***
Private Entity (Sponsor)	Civil Works & Preparation	4,460,000
	Production drilling	12,400,000
	Field Development	6,000,000
	Construction of Power Plant	35,220,000
	Transmission Line (2 lines)	18,000,000
	Subtotal	***76,080,000***
	Consultancy Services (DD, SV)	3,040,000
	(ESIA)	200,000
	(Tender)	0
	Subtotal	***3,240,000***
Total		***79,320,000***
Grand total		***111,060,000***

出典：JICA調査団

Model-3		
Organization in Charge	**Cost Items**	**Cost (USD)**
Public Entity (Gov)	Civil Works & Preparation	0
	Slimhole Drilling (3 Wells)	0
	Appraisal Drilling (4 Wells)	0
	Production Drilling (2 Wells, Production Test)	0
	Subtotal	*0*
	Consultancy Services (DD, SV)	0
	(ESIA)	0
	(Tender)	750,000
	Subtotal	750,000
Total		***750,000***
Private Entity (Sponsor)	Civil Works & Preparation	13,700,000
	Appraisal Drilling (4 Wells)	20,800,000
	Production Drilling (2 Wells, Production Test)	12,400,000
	Field Development	6,000,000
	Construction of Power Plant	35,220,000
	Transmission Line (2 lines)	18,000,000
	Subtotal	***106,120,000***
	Consultancy Services (DD, SV)	4,240,000
	(ESIA)	200,000
	(Tender)	0
	Subtotal	***4,440,000***
Total		***110,560,000***
Grand total		***111,310,000***

Model-4		
Organization in Charge	**Cost Items**	**Cost (USD)**
Public Entity (Gov)	Civil Works & Preparation	0
	Slimhole Drilling (3 Wells)	0
	Appraisal Drilling (4 Wells)	0
	Production Drilling (2 Wells, Production Test)	0
	Subtotal	**0**
	Consultancy Services (DD, SV)	0
	(ESIA)	0
	(Tender)	750,000
	Subtotal	**750,000**
Total		**750,000**
Private Entity (Sponsor)	Civil Works & Preparation	13,700,000
	Appraisal Drilling (4 Wells)	20,800,000
	Production Drilling (2 Wells, Production Test)	12,400,000
	Field Development	6,000,000
	Construction of Power Plant	35,220,000
	Transmission Line (2 lines)	18,000,000
	Subtotal	***106,120,000***
	Consultancy Services (DD, SV)	4,240,000
	(ESIA)	200,000
	(Tender)	0
	Subtotal	***4,440,000***
Total		***110,560,000***
Grand total		***111,310,000***

出典：JICA調査団

表 5-6　事業の実施スケジュール

MODEL 1		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Public Entity (Gov)	Civil Works & Preparation	■		■						
	Slimhole Drilling (3 Wells)		■							
	Appraisal Drilling (4 Wells)				■					
	Production Drilling (2 Wells)					■				
	ESIA	■				■				
	Tender						■			
Private Entity (Sponsor)	ESIA							■		
	Field Development							■	■	
	Transmission Line							■	■	
	Construction of Power Plant									■

MODEL 2		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Public Entity (Gov)	Civil Works & Preparation	■		■					
	Slimhole Drilling (3 Wells)		■						
	Appraisal Drilling (4 Wells)				■				
	ESIA	■							
	Tender					■			
Private Entity (Sponsor)	Civil Works & Preparation						■		
	Production Drilling (2 Wells)						■		
	ESIA						■		
	Field Development						■	■	
	Transmission Line						■	■	
	Construction of Power Plant								■

MODEL 3		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Public Entity (Gov)	Civil Works & Preparation	■								
	Slimhole Drilling (3 Wells)		■							
	Tender			■	■					
	ESIA	■								
Private Entity (Sponsor)	Civil Works & Preparation					■		■		
	Appraisal Drilling (4 Wells)						■			
	Production Drilling (2 Wells)							■		
	ESIA							■		
	Field Development							■	■	
	Transmission Line							■	■	
	Construction of Power Plant									■

MODEL 4		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Public Entity (Gov)	Tender	■	■					
Private Entity (Sponsor)	Civil Works & Preparation			■		■		
	Appraisal Drilling (4 Wells)				■			
	Production Drilling (2 Wells)					■		
	ESIA			■		■		
	Field Development					■	■	
	Transmission Line					■	■	
	Construction of Power Plant							■

出典：JICA調査団

5−7　財務経済分析

5−7−1　グレナダにおける地熱開発プロジェクトの財務分析

グレナダ政府は地熱資源の開発を促進するにあたって、官民連携での開発を目指している。本稿では、政府が官民連携のためにおこなう投資オプションを比較し、プロジェクトの財務的実施可能性を評価するために、財務分析を行う。この分析は、開発スキームの可能性、資金調達の可能性について評価する上で有効である。

(1)　プロジェクトスキーム

グレナダの地熱発電プロジェクトでは、政府が調査から発電所の運営まで一貫して開発主体となることは、実際の組織、財務、人材、法制度などの点から想定し難い。従って、開発のいずれかの段階で民間企業の参加を得て、開発を進めることが必須条件であると考えられる。プロジェクトの財務評価は、民間企業が事業に参加するタイミングで異なってくるので、本稿では幾つかのオプションを想定し財務分析を進める。

本分析では、3 つのプロジェクトスキームを検討する。モデル 1 からモデル 3 は、政府と民間企業がプロジェクト実施に必要な活動を分担して行う官民連携のオプションを示している。またスリムホールについては、政府が無償資金を調達して実施することを想定する（表 5-4 参照）。

さらに、条件次第では民間企業がスリムホールを実施せずに評価井の掘削から事業参加をすることが想定される（モデル 4）。これは伝統的な BOT(Build Operate Transfer)の民間投資スキームと考えられる。ただし、このモデル 4 は、民間企業がスリムホールの実施を行わない場合のモデル 3 と財務分析上同等に扱うことができるので、モデル 4 の BOT の財務分析は本分析からは除外する。

政府が実施する事業の投資回収は、コンセッション契約によって発電所開発を行う民間事業者からのロイヤリティー収入によって行うことを想定する。この料金は民間発電事業者の営業費用として計上される。一方民間発電事業者は、GRENLEC に売電することによって収益を得ると仮定する。発電事業者は、一般の民間企業に加えて GRENLEC や政府が株主として事業参加する場合も考えられるが、本分析ではこの様なケースは想定しない。発電事業者にはエクイティ IRR（20%程度）を仮定する。

表 5-7 に、プロジェクトスキームの諸前提を示す。

表 5-7 プロジェクトスキーム

項目		モデル 1 発電所分離 (PPP モデル No.1)	モデル 2 生産井分離 (PPP モデル No.2)	モデル 3 評価井分離 (PPP モデル No.3)
Development Activity & Entity	1. スリムホール	無償資金による政府実施	無償資金による政府実施	無償資金による政府実施
	2. 評価井	政府実施	政府実施	民間企業実施
	3. 生産井	政府実施	民間企業実施	民間企業実施
	4. 発電設備開発	民間企業実施	民間企業実施	民間企業実施
	5. オペレーション	民間企業実施	民間企業実施	民間企業実施
借入金	政府	譲許性融資	譲許性融資	譲許性融資
	民間企業	商業ローン	商業ローン	商業ローン
政府の資金回収方法		蒸気売買契約もしくは生産井戸の売却	発電会社に対する評価井の費用移転	費用移転は発生しない
民間の資金回収方法		発電した電力を GRENLEC に販売		

出典：JICA調査団

(2) 開発計画

開発計画概要では上記で述べた 3 つのモデルを取り扱う。これらのモデルの主な相違点はプロジェクトの活動を担当する組織が異なるが、個別の投資項目の基本的な物理的費用は共通していると仮定する。これらのモデルの相違点は、資金コスト、プロジェクト実施のスケジュール、オペレーションにかかる法人税、その他政府の許認可事項などが主である。

表 5-8 に開発計画の概要を示す。

表 5-8　開発計画概要

1. プロジェクト概要	
1.1 プロジェクト内容	
プロジェクトには次の活動が含まれる。 - 地熱資源の評価 - 井戸掘削とテスト - 地熱発電所の建設 (15MW あるいは 10-15 MW 程度を想定) - 送電線の建設（今後 GRENLEC と協議予定） - 発電所の運転・維持管理	
1.2 プロジェクト目標・目的	
- 電気料金の低減と安定化 - 地球温暖化ガス低減への貢献	GRENLEC への売電コストは 0.15 US$/kWh 程度を想定。
1.3 意思決定	
- 現時点において、プレ可能性調査を実施中。 - 並行して、資金調達の可能性について検討中。	開発の段階は次の 6 つに分類される。 1. 開始初期段階, 2. 資源評価 , 3. 資源の定量化, 4. 資源確認, 5. 建設, 6. 運転
1.4. プロジェクトガバナンス	
プロジェクト実施体制については現在検討中。	
1.5 政策・法制度枠組み	
法制度: - Public Utilities Regulatory Communication Bill 2015: 2016 年 6 月に国会にて承認された。 - Electricity Supply Bill 2015: 同上 - Geothermal Development Bill: 検討中。 政策： 財務省のエネルギー局がエネルギー政策を担当。	官民連携関連の法制度も今後検討。
2. 投資	
2.1 一般	
主要な調達は国際基準に従って、公開入札によって行われる予定。	

2.2 コスト積算

モデル３のコストは次の通り。

(i) 政府関連コスト

井戸掘削	土木工事	井戸掘削	%
井戸掘削	土木工事	0	0.0
	スリムホール	0	0.0
	評価井	0	0.0
	生産井	0	0.0
	コンサルティング	0.75	100.0
発電所	フィールド開発	0	0.0
	発電所	0	0.0
	送電線	0	0.0
	コンサルティング	0	0.0
合計費用		0.75	100.0

(ii) 民間企業関連コスト

井戸掘削	土木工事	井戸掘削	%
井戸掘削	土木工事	13.10	11.89
	スリムホール	0.00	0.0
	評価井	20.80	18.87
	生産井	12.40	11.25
	コンサルティング	4.08	3.70
発電所	フィールド開発	6.60	5.90
	発電所	35.22	31.96
	送電線	18.00	16.34
	コンサルティング	0.00 (上記に含む)	0.00
合計費用		110.20	100.0

コストには、土木工事、掘削、発電所建設、蒸気関連設備などの調達費用が含まれる。

送電線コストは、暫定的に今回のコストに含めており、これは今後 GENLEC と協議を行う予定。

その他のモデルについてはすでに 5-4 章にてまとめた通り。

2.3 プロジェクト・プロファイル

基本ケースとして次を想定。

- 発電容量　: 5.5 MW x 3 基, 合計 16.5 MW
- 所内率　: 10%
- 稼働率　: 90%
- 正味発電容量　: 15 MW
- 発生電力量　: 118.2 GWh/年
- 建設期間　: モデルによって異なる
- 運転期間　: 30 年

2.4 プロジェクトスケジュール

モデル 3 における標準スケジュールは次の通り。

項目	期間（年）	備考
許認可・土木工事	1.0	政府による実施
スリムホール	1.0	
入札	2.0	
土木工事および実施準備	1.0	民間による実施
評価井掘削	1.0	
生産井およびフィールド開発	1.0	
送電線建設	1.0	
発電所建設・運転開始準備	1.0	
合計	9.0	

その他のモデルについてはすでに 5-4 章にてまとめた通り。

出典：JICA調査団

(3)　財務分析にかかる前提条件

分析にかかる前提条件を表 5-9 に示す。条件は現時点での類似プロジェクトを参照に標準的な設定とした。

表 5-9　分析にかかる前提条件

項目	条件
a. 発電量	118.2 GWh/年 (平均稼働率；90%)
b. 初期投資額	110.20　US$ mil. (モデル３の民間企業参考)
c. 建設期間	モデルによって異なる
d. プロジェクト期間	25 年間運転
e. 借入金・資本金比率	モデルによって異なる
f. 借入金返済条件	譲渡性資金: 25 年返済、7 年返済猶予 商業ローン: 20 年返済、3 年返済猶予
g. 借入金コスト	譲渡性資金利子率 : 3.0 % 商業ローン利子率 : 5.5 %
h. 年間運転費用	総建設費の 2.0%
i. 加重平均資本コスト	モデルによって異なる
j. 減価償却	耐用年数: 25 年、残存価値: 5%, 定額法
k. 租税公課	法人税：30%, 付加価値・輸入関税免除
l. 物理的予備費	工事費の 5%
m. 売電単価	GRENLEC への売電単価: US 15.0 cents/kWh
n. 井戸掘削費用チャージ	政府から発電会社へのチャージ；モデルによって異なる

出典：JICA調査団

借入金については、国際金融機関などの援助機関、商業銀行などにおける公的機関、民間企業への貸付実績や現行のトレンドを参考に譲許性融資と商業貸付けのそれぞれについて

条件を仮定した。また、民間企業のエクイティ IRR として 20%を前提とした。減価償却については発電所の耐用年数と同等の期間を設定した。

(4) 財務分析結果

【GRENLEC への売電単価を US 15.0 cents/kWh とした場合】

GRENLEC へのヒアリングによれば、地熱発電での売電価格が US 15.0 cents/kWh 程度であれば地熱発電所から買電してもよいとしている。従い、本分析では、地熱発電での売電価格が US 15.0 cents/kWh と仮定する。ただし、本計画では地熱発電所からセントジョージズの変電所までの送電線建設費もプロジェクトコストに含める必要があるので、本分析では送電端単価を US 15.0 cents/kWh と仮定する。

これによる財務分析の結果を表 5-10 に示す。

表 5-10 財務分析結果

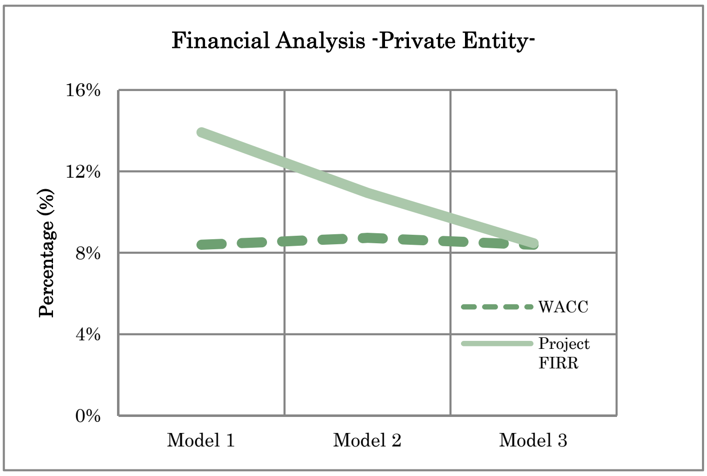
(GRENLEC への売電価格を 0.15 USc/kW と仮定した場合)				
組織	項目	モデル 1	モデル 2	モデル 3
政府	借入金[4]	US$ 41.5 mil.	US$ 27.1 mil.	US$ 0.6 mil.
	資本金	US$ 20.1 mil.	US$ 13.5 mil.	US$ 0.3 mil.
	加重平均資本コスト[5]	2.6%	2.6%	2.6%
	プロジェクト FIRR	3.8%	3.9%	4.4%
	エクイティ FIRR	0.1%	0.0%	2.0%
民間	借入金	US$ 50.3 mil.	US$ 66.3 mil.	US$ 92.6 mil.
	資本金	US$ 12.6 mil.	US$ 19.1 mil.	US$ 23.1 mil.
	加重平均資本コスト	8.4%	8.7%	8.4%
	プロジェクト FIRR	13.9%	11.0%	8.5%
	エクイティ FIRR	34.9%	31.8%	22.2%
官民合計	プロジェクト FIRR	8.9%	8.4%	8.4%

出典：JICA調査団

すべてのモデルにおいて政府は民間企業から投資費用を回収できることを前提とする。当然ながら、この回収する費用の原資は、エンドユーザーが配電会社に支払う電気料金が原資となる。また、財務分析の評価は、加重平均資本コスト（WACC）とプロジェクト IRR を比較することによって行い、プロジェクト IRR が WACC を下回らないときに、プロジェクトは財務的にフィージブルであると判断する（図 5-4）。

[4] 借入金は建中利子を含まない金額。

[5] WACC: Weighted Average Cost of Capital, FIRR: Financial Internal Rate of Return



出典：JICA調査団

図 5-4 財務分析結果「民間企業」

分析の結果、すべてのモデルにおいて、プロジェクト IRR は WACC を上回る結果となった。このため、本プロジェクトはすべてのモデルにて財務的に実施可能である判断される。

【モデル毎の特徴】

モデル 1 において政府は生産井までの開発活動を行うことを仮定しているため、民間企業の投資必要額は他のモデルに比べて少ないものとなっている。このため、民間のエクイティ IRR は高いものとなっている。また、地熱開発を推進する上で最も投資リスク高い「地熱資源開発リスク（生産井戸が得られないリスク）」を民間企業は完全に回避することができる。民間企業側から見るとこのモデルは、最も投資効率は高いモデルである。一方、「地熱資源開発リスク」は政府側が負うことになり、政府側の資金調達が課題になる。

モデル 2 においては、政府関与は評価井までにとどまり、生産井が建設されないことから、モデル 1 に比べて民間企業の投資額が増大し、資源開発リスクもやや増加する。ただしこのモデルでは評価井によって地熱資源量の推定が政府事業において終了しているため、生産井掘削に一定のリスク（成功率）を見込むことによってある程度の費用予測可能となる。従って、民間企業としては参入のための技術的ハードルがモデル 1 に比較して低くなることが期待される。

一方、**モデル 3** においては、民間企業が評価井、生産井に投資をする必要があり、このため他のモデルにくらべて民間企業のエクイティ IRR は小さいものとなっている。加えて、スリムホールによる調査だけでは信頼性の高い資源量評価は容易ではないことから「資源開発リスク」が増大し、民間企業の投資意欲を低下させる可能性低がある。ただしこの場合においてもエクイティ IRR は加重平均資本コストを上回っており、一定の投資妥当性は確認された。

以上より、すべてのモデルにおいて民間企業は必要な投資回収が可能であるという分析結果となった。ただし、民間企業からの投資を促進するためには、政府から民間企業への課金は必要最小限に抑えることが望ましいことは言うまでもない。

なお、官民合計のプロジェクト IRR はすべてもモデルにおいて約 8%程度にとどまっている。これは政府が実施する試掘ステップや民間企業の事業参加にかかる入札にある程度の期間を要し、調査から発電所運転開始までの期間が標準でも 9 年程度の建設期間がかかることが影響していると思われる。

【エクイティ IRR を 20%と固定した場合の売電価格分析】

上述の財務分析の基本的考え方は、発電会社から配電会社への売電価格を固定して、プロジェクトの経済性を評価したものである。これに対して、発電会社のエクイティ IRR を固定して、プロジェクトの経済性を分析した結果は、表 5-11 のとおりとなる。

表 5-11　売電価格分析

Assumption	Indicator		モデル 1	モデル 2	モデル 3
Equity IRR (20%)	Power Sales Tariff	US cents /kW	12.1	12.9	14.3

出典：JICA調査団

エクイティ IRR を 20%と仮定して売電料金を計算した結果は、モデル 3 では約 US 14 cents/kWh、モデル 1 においては約 US 12 cents/kWh まで低減が可能であることがわかる。GRENLEC へのヒアリングによれば、GRENLEC の受電端価格が US 15 cents/kWh 程度であれば買電できる範囲であると述べているので、これらの分析結果は地熱発電の実施によって現行の電力価格を低減できる可能性があることを示している。

(5)　考察と提言

現時点での調査精度においてプロジェクトの投資妥当性について確認することができた。今後プロジェクトを進めるうえで次の点を考慮すべきであると考える。

a. 政府の役割と資金調達

政府の役割はプロジェクト投資に民間企業を誘致し、プロジェクト実施を促進させることであると考える。これを実施するためには、政府は試掘段階（当面はスリムホール、必要に応じて評価井）での資金調達を確保することがまず重要である。政府による試掘活動実施によってプロジェクトリスクが低減され、民間投資家への動機付けを与える効果が指摘される。これは政府関与により、民間企業の「資源開発リスク」の低減と「エクイティ IRR」の増加がが期待できることよる。

分析ではスリムホールの資金を無償資金にて対応することを前提条件としている。また評価井以降では無償資金は分析上考慮していない。無償資金による評価井掘削は一般的なプラクティスとなっていないと考えられるからである。従って、政府あるいは民間企業は

評価井移行の地熱井掘削に関して無償資金以外のリスク低減スキームや譲許性融資資金の調達を検討することが求められる。

b. 政府の投資政策

政府資金の出資金にかかる投資政策について検討することが求められる。分析では政府のエクイティ IRR は極めて低く抑え、民間企業への配慮を行った。これは民間企業の入札において優位な条件を民間企業に提示するためである。この課題については、政府から民間企業への課金レベルを議論することによって対応できる。つまり、プロジェクト全体の便益を政府と民間企業でどのように配分するかということを検討すべきである。

c. 能力開発

プロジェクトを実施していくため政府は能力開発を進めるべきである。プロジェクトはまだ初期段階にあり、今後政府は地熱資源の評価、プロジェクト実施の可能性調査を進めて行く必要がある。また、プロジェクトにかかる民間企業との入札、契約などについては政府が監理していくことになる。これらは、プロジェクトの資金調達に加えて重要である。ただし、今後のグレナダ国における地熱開発事業はある程度限定されると考えられることから、これらの個別スキルの全てを政府職員が修得する必要性はなく、事業を推進上の施策立案やプロジェクト進捗管理等の行政としての必要最小限の能力開発に集中することが肝要と考える。これら業務は、政府のプロジェクト・マネジメントオフィスの所掌範囲である。

d. 法制度整備

プロジェクト実施のためには、既存法制度の合理化や新制度の整備などが求められる。必要な法制度を確立することによって、民間企業の投資に対して呼び水的な効果があることはいうまでもない。これらの法制度には、地熱開発法、Public Utilities Regulatory Communication Bill 2015, Electricity Supply Bill 2015 や官民連携にかかる法制度が含まれる。また、地熱発電所にかかる技術基準やモニタリング指針なども適切に整備することが必要である。また、ESIA 関連制度の整備も急務と考えられる。

e. 調査精度向上

調査は現時点ではまだ Pre-FS 程度の初期段階である。今後、追加調査、試掘ボーリングなどを行っていく過程において、発電所計画、工事費を精査しプロジェクト実施可能性の精度を向上させることが求められている。これらの見直し項目としては、資源量、設計施工技術、コスト積算、資金調達オプション、建設スケジュール、官民における役割分担などが含まれる。

通常、調査の精度が上がるに従って工事費が増加し、エクイティ IRR は低下する傾向が見られている。従って、調査項目を検討し精度に配慮しながら調査計画を進めることが重要である。

f. マーケット・サウンディング

財務分析の前提条件は現時点での想定にて実施をしており、今後の調査進捗に従って見直し、調整をすべきことはすでに述べた通りである。特に民間事業者や融資機関はまだ決定しているわけではなく、今後、興味のある事業者、金融機関、市場関係者とは必要に応じて適切に情報交換を行い、今後の事業検討の参考にすべきであると考える。

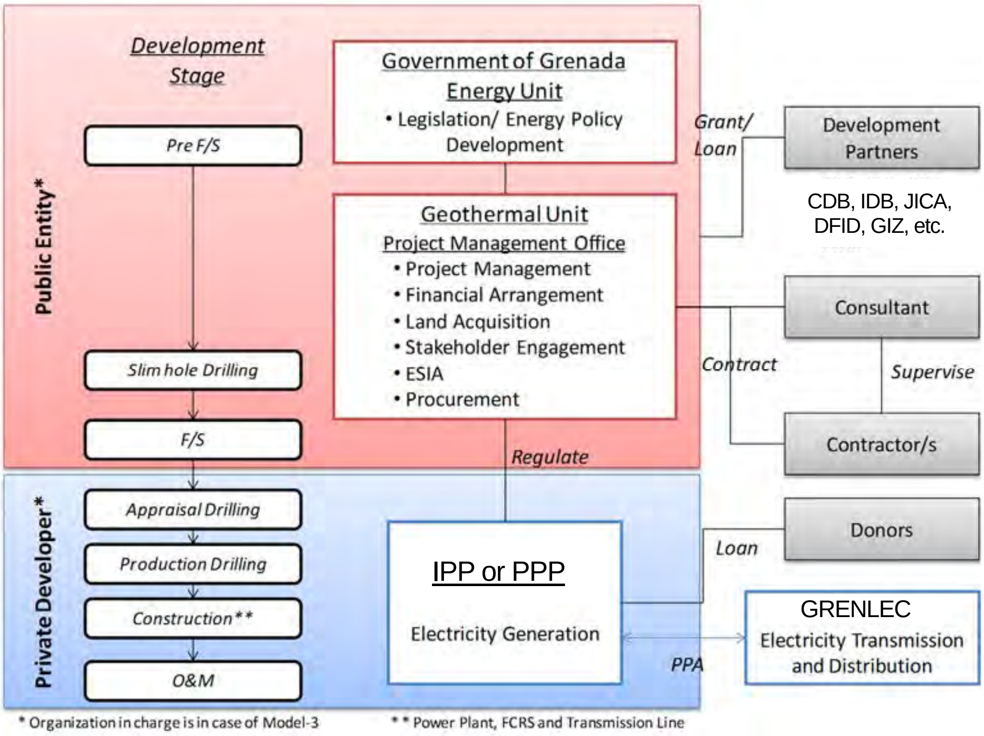
財務分析で検討したモデル 1 から 3 の検討を深めるためには、技術的、財務的な検討に加えて市場の動向、特定の企業とのマッチングが非常に重要である。政府のプロジェクト政策と利害関係者の期待が必ずしも一致するわけではないため、その調整が重要なタスクとなると想定される。

5－8 プロジェクトの実施体制

グレナダ国における地熱開発プロジェクトの実施体制を下図に示す。ここでは典型的な例として、プロジェクスリムホール掘削までがグレナダ政府、それ以降は民間企業が事業参加するプロジェクトスキームを例に取り上げる（モデル 3）。

F/S ステージまでの実施体制としては、グレナダ政府は地熱開発プロジェクトを推進するために必要な法制度の整備、ならびに電力政策ポリシーを成立させる。一方プロジェクトの進捗管理については、Energy Unit 配下に地熱開発の特別組織（Geothermal Unit）を設置して、地熱開発に専従させることを想定する。Geothermal Unit では地熱プロジェクトの管理業務を掌握し、テスト井掘削のための資金調達、土地収用、および、ESIA ならびに掘削業務の調達・入札・契約の管理などの地熱開発に必要な政府側の業務を担当する。

掘削工事､ならびにESIA 調査の技術的管理は専門コンサルタントにより実施されるものとし、コンサルタントは直接グレナダ政府、または各ドナーにより調達される。



出典：JICA調査団

図 5-5　地熱開発プロジェクトの実施体制

5−9　　プロジェクト評価　DAC 評価 5 項目

5−9−1　　妥当性（Relevance）

開発ニーズとの整合性：グレナダ国では、再生エネルギー利用の促進と低炭素型発電の移行を国家エネルギー政策の一つとしている。本地熱発電所建設計画は、この国家目標に合致するものである。

国際支援の方向性との整合性：国際社会では地球温暖化対策の一環として低炭素社会の実現に向けて再生可能エネルギーの利用を促進している。グレナダ国のこの地熱発電所建設計画は、この国際社会が達成を目指す方向性とも一致し、支援を得やすい事業である。

手段としての適切性：地熱資源はグレナダ国地産の再生可能エネルギーなので国家目標と合致している。また、複数のドナーの支援も受けやすく、事業実現の可能性も高い。

5−9−2　　有効性の予測　　(Effectiveness)

事業目標の内容：設備容量 5 MW x 3 ユニットの地熱発電所の建設、送電線の建設。

事業の内容およびアウトプットは明確である。外部条件（後述）が満たされれば、事業の目標は確実に達成される。

5－9－3　効率性の予測　（Efficiency）

経済分析の結果、外部条件が満たされれば本事業は財務的にフィージブルであると判断できる

5－9－4　インパクトの予測（Impact）

本事業の実現によって、地産の低炭素エネルギーの活用が促進され、その結果上位目標に貢献できる。

【波及効果】

社会環境：	電力供給の安定化、低価格化によって、全島住民が裨益しかつ経済活動が活性化する。ただし、現在電力独占企業の経営に悪影響をあたえ、その従業員へ影響が波及する可能性がある。土地収用、住民移転が発生する可能性がある。
自然環境：	工事中の影響、運開後の影響を適切にアセスメントを実施する必要がある。

5－9－5　持続性の予測（Sustainability）

地熱発電は気候変化に影響されない地産のエネルギーで運用できる。従い、以下の課題を政府ないし事業者が解決することによって、事業の持続性は確保される。

政策・制度：	事業運営のための法律、関連法規は現在整備中であり、整備後は政策制度面で事業継続が指示される。
体制：	事業は地熱発電事業の経験豊富な民間企業の参入を促し、IPP あるいは PPP によって実施される。
財務面：	適切な電気料金の設定によって、財務の健全性は確保される。
技術面：	経験豊富な民間企業によって行われる。
社会・文化・環境：	適切な排気、排水処理が行うことにより持続性は確保される。ジェンダー、貧困層、社会的弱者への影響はない。

5－9－6　外部条件（External Conditions）

想定される主な外部条件は以下の通り。

- 事業促進のための無償資金ないしは有償資金が調達される。
- 資源確認および地熱発電所建設にかかる技術支援が行われる。
- 地熱資源が確認され、開発される。
- 民間企業が参入し、IPP ないしは PPP による事業が創生される。

5－9－7　総合評価

以上のとおり、前項で示した外部条件が満足されれば、本地熱発電所建設事業は、フィージブルと判断する。

5−10　プロジェクト資金の見通し

本地熱開発プロジェクトの資金源として考えられるスキームを以下に示す。

表 5-12　プロジェクト資金の見通し

種類	開発パートナー	適用
無償資金	CDB, IDB, Bilateral donors (e.g. UK)	ー試掘井掘削
融資	CDB, IDB (e.g. Clean Technology Fund), Bilateral donors (e.g. JICA), IRENA	ー資源評価井掘削、 ー生産井掘削、 ー発電所建設、 ー送電線建設 ーコンサルティングサービス
技術協力	Bilateral donors (e.g. NZ, JICA), Other organizations (e.g. UN organizations)	ープロジェクト推進能力向上支援 ーESIA 実施 ー掘削を含む建設工事にかかる技術支援（仕様書作成、入札支援、施工監理、井戸試験実施などを含む）

出典：JICA調査団

第 6 章　案件実施に向けたアクションプランと課題

6－1　案件実施に向けたグレナダ政府のアクションプラン

グレナダにおいて地熱開発プロジェクトを実現するにあたって、政府機関、ドナーならびに民間事業者、それぞれにアクションが示される（図 6-1）。

プロジェクトの開発ステージは 2016 年現在で Exploration まで終了しており、今後はテスト井（スリムホール）掘削に向けた準備が開始される。2025 年の地熱発電所の運転開始をターゲットにしたアクションプランを以下に示す（モデル 3）。

グレナダ政府は同国のプロジェクト投資に民間企業を誘致し、プロジェクト実施を促進させるための試掘実施に向けて、当面は以下を実施する必要がある。

6－1－1　直近のアクション

a. 法制度整備（2016~2020 年）
- 地熱開発ユニットの設立
- 地熱開発法、Public Utilities Regulatory Communication Bill 2015, Electricity Supply Bill 2015 や官民連携にかかる法制度
- 地熱資源法の整備
- ESIA 関連制度の整備（IFC 等準拠）
- 法制度整備にかかる技術支援（アドバイザー等）調達

b. 技術支援、無償資金の調達（2016 年）
- 地熱開発ユニットの行政能力向上のための無償技術支援調達
- 試掘かかる ESIA 実施のための無償技術支援調達
  - ベースライン調査、スコーピング
  - 試掘のための ESIA（Stakeholder Engagement を含む）
- 無償技術支援の調達
  - 試掘のための入札図書作成と業者調達支援（項目 d. 施工監理、技術管理、次期計画策定も含む）
- 試掘のための無償資金の調達

c. 試掘用用地借用（2016～）

d. 試掘業者調達、試掘実施（施工監理、技術評価、次期計画策定を含む）（2017～）

6－1－2　試掘終了後の事業推進に備えるアクション

a. 事業実施機関（IPP ないし PPP）のサウンディング、融資元のサウンディング、融資条件等調査（2016～）

b. 資源量評価井戸関連 ESIA のための融資資金調達、ないし（有償／無償）技術支援調達サウンディング（2016～）

c. 買電会社との PPA 交渉

6－1－3　資源量評価井の掘削に係るアクション

a. 事業者選定、事業形態組成（IPP ないし PPP）

b. 資源評価井掘削 ESIA 調査（Stakeholder Ingagement を含む）

c. 事業者による、資源評価井掘削資金調達（融資による）

d. 事業者による、資源評価井掘削にかかる用地取得

e. 資源評価井掘削工事、資源評価解析

f. F/S 調査

g. 買電会社との PPA 締結

6－1－4　施設建設工事開始に備えるアクション

a. 追加生産井掘削、地上蒸気輸送施設、発電所建設、送電線建設にかかる ESIA 調査（Stakeholder Ingagement を含む）

b. 事業者による建設資金調達（融資）

c. 事業者による用地取得

d. EPC 調達

○ 施設建設工事

a. EPC による施設建設工事

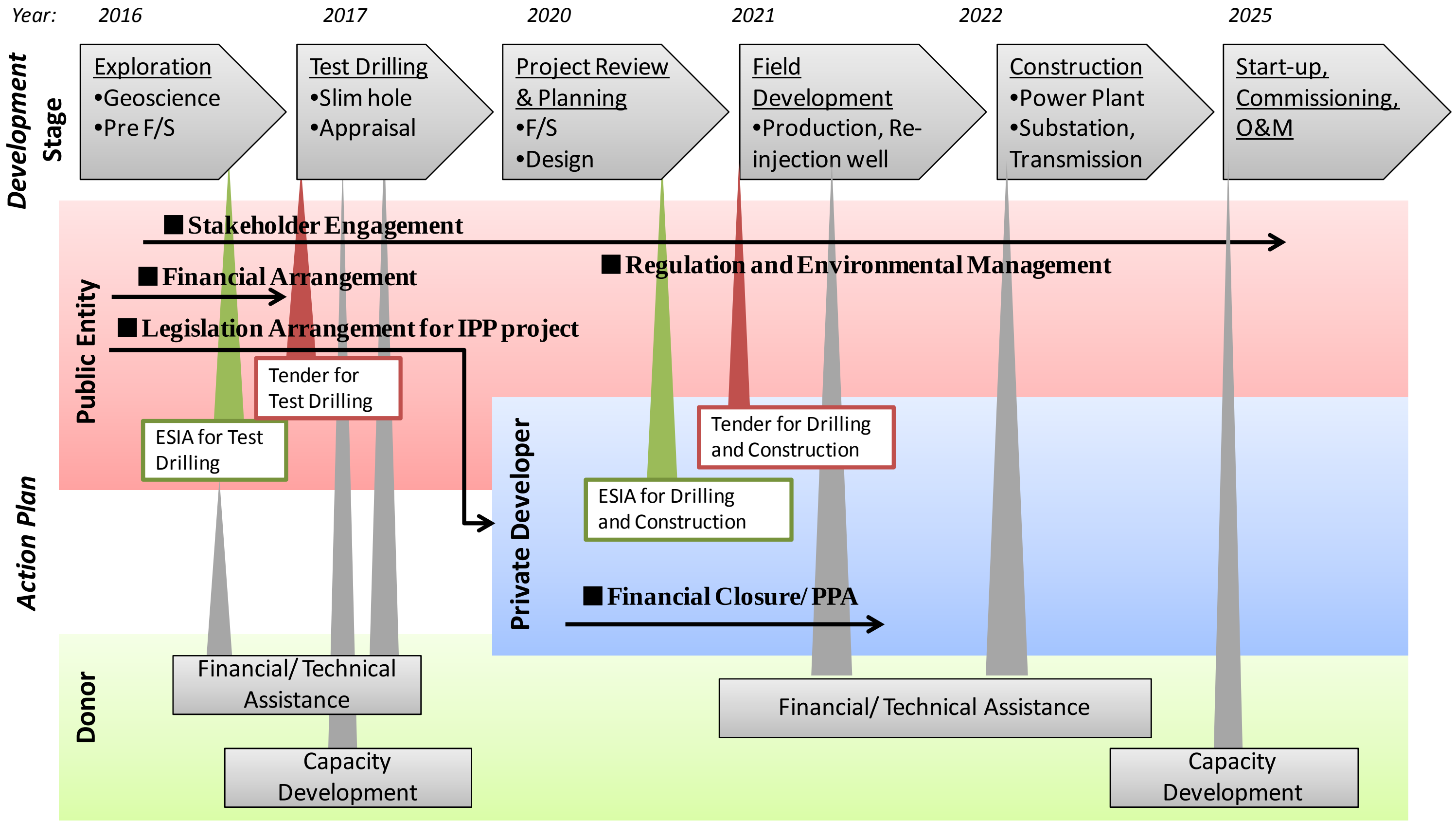
b. 事業者による工事施工監理

○ 運転開始（2025）

a. コミッショニングテスト期間

b. 施設引き渡し（EPC→事業者）

c. 事業者による O&M



出典: JICA調査団

図 6-1 地熱開発に向けたアクションプラン

6−2 本邦からの支援

上記で記述したグレナダ政府のアクションのうち、本邦からの支援が考えられる項目は下記の通りである。

- 試掘にかかる ESIA 実施のための技術支援
  - ➢ ベースライン調査、スコーピング
  - ➢ 試掘のための ESIA（Stakeholder Ingagement を含む）
- 無償技術支援の調達
  - ➢ 試掘のための入札図書作成と業者調達支援（施工監理、技術管理、次期計画策定も含む）
- 試掘のための無償資金の調達

6−3 結論

(1) 地熱資源開発の必要性

- グレナダ島の電力は、ディーゼルエンジン発電施設で発電されている。このため、電力価格は原油価格の変動を強く受けている、2008 年には一般家庭用電気料金が 0.81 EC$ (US$ 0.30/kWh)を超える水準まで高騰した。
- この様な背景から、自国地産資源である地熱資源の開発が急務である。

(2) 地熱資源

- グレナダ島には、20−95 MW 程度と推定される、地熱資源が賦存する可能性がある。

(3) 地熱開発計画

- この資源を利用して、設備容量 15 MW の地熱発電所の建設は、財務的にフィージブルと判断される。
- DAC の評価 5 項目の観点でプロジェクト評価を行った結果、本プロジェクトの実施はフィージブルと判断される。
- ただし、外部条件として掲げた 6 項目がクリアされる必要がある。
  - ➢ 関連法制度が施行される。
  - ➢ 事業促進のための無償資金ないしは有償資金が調達される。
  - ➢ 資源確認および地熱発電所建設にかかる技術支援が行われる。
  - ➢ 地熱資源が確認され、開発される。
  - ➢ 民間企業が参入し、IPP ないしは PPP による事業が組成される。
  - ➢ ESIA 関連の条件がみたされる。

(4) 構造試錐井掘削

- 地熱開発計画を確実にするため、3 本の構造試錐の掘削が必要である。

6−4 提言

プロジェクトを速やかに実施にするために以下の項目の実施を提言する。

1. 地熱開発ユニットの創設および事業推進にかかる能力向上プログラムの導入
2. 関連法制度の整備
3. 試掘にかかる技術支援ないし無償資金調達、
4. 試掘にかかる ESIA の実施、試掘調査の実施および資源賦存有無の確認
5. 資源量評価井掘削にかかる融資元サウンディング
6. 地熱発電事業にかかる民間企業、融資策等のマーケット・サウンディング

添付資料

添付資料-1　協議議事録

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

Minutes of Meeting (Memorandum within the Survey Team)

<table>
<tr><td>Meeting</td><td>Kick off meeting with Ministry of Finance and Energy</td><td>Venue</td><td>Financial Complex</td></tr>
<tr><td>Date</td><td colspan="3">2015/5/12 9:30-11:15</td></tr>
<tr><td>Participants</td><td colspan="3">[From Grenada side]
1. Mr. John Auguste (JA), Senior Energy Officer, Ministry of Finance and Energy
2. Mr. Christopher Joseph (CJ), Energy Officer, Ministry of Finance and Energy
[From Japan side]
1. YAMAGUCHI Kazutoshi (YK), Latin America and the Caribbean Department, JICA
2. TADA, IDB (through internet)
3. CDB not connected due to network problem
[JICA Survey Team]
1. TAKAHASHI Shinya (ST), Team Leader/ Geothermal Energy Development/ Reservoir Assessment
2. AKATSUKA Takashi (TA), Vice Team Leader/ Geology/ Drilling Planning
3. FUKUDA Daisuke (DF), Geochemistry
4. KAWASAKI Kiyoshi (KK), Geophysical Survey
5. KIKUKAWA Takeshi (TK), Electricity Policy/ Investment Policy
6. TERAMOTO Masako (MT), Environmental Social Consideration
7. Saul PADILLA (SP), Project coordination</td></tr>
<tr><td>Material</td><td colspan="3">1. Inception Report
2. PPT-Inception Presentation
3. PPT-Financial Aspect in Geothermal Development</td></tr>
<tr><td>Agenda</td><td colspan="3">1. Opening speech from Ministry of Finance and Energy
2. Speech from JICA and IDB
3. Introduction from JICA Survey Team
4. Presentation 1 on Inception Report from JICA Survey Team
5. Presentation 2 on Financial Aspects from JICA Survey Team
6. Discussions
7. Closing</td></tr>
<tr><td>Record of Meeting</td><td colspan="3">1. From Ministry of Energy
- Introduction by Mr. Christopher Joseph. He thanks of our visit to Grenada and they are grateful that Japan and others (IDB and CDB) are interested to contribute with assistance to Grenada to be able to develop the geothermal energy in the country.
- CJ: The information that was required previously to this office can be partially provided during the meeting and can be complemented before the team leaves the country on Saturday.
2. From IDB
- Through the phone, IDB explained the objectives of this mission and thanks for the attention to the team.
- YK: requested access to the information of the NZ Company. Mr. JA said that is not completed yet, but they expect to have it in 2 months and they are able to share it with us.
-
3. From Japan side
- ST: Introduced the team members participating in the survey during this week, including Mr. Yamagushi as the responsible of JICA for the Caribbean countries.
4. Presentation 1: <u>Inception Report</u> and its objectives of this mission are defined. Following are some comments during the presentation.
- It is confirmed that, recently a NZ company (JACOBS) has conducted some exploratory studies in Grenada.
- At moment NZ Company is still working in the final report, as soon they send it to this office, it will be shared with JICA team in order to review it and make a proper revision. From this revision it will be decide what other studies needed to additionally. The idea is not to duplicate works of both parties.
- CJ explained that the NZ company proposed to make studies 3-G including Geology, Geochemistry and Geophysics and conduct MT survey at 50 points (Actually 60 points by information from Jacobs),.
- ST asked if the scope of NZ company include environmental and social survey, in case it is not included we can assist in this matter. JA said that he is not sure but he will see.
- ST mentioned that GRENLEC owns 50% of the electricity generation company and asked for who is the responsible in the country for the geothermal development project, is it the Government or GRENLEC?
- CJ explained it is taking back under the control of the Ministry of Energy. The ides is not to own the generation company but to take the control of regulations. For this purpose, the government is redacting the Electricity Supply Act with the assistance of World Bank to make it official and it will not affect the existing installations, but, from now, every new energy project will be regulated with this Act.
- (From the comments of Mr. Christopher explained, it is understood, that in 1994 the government sold</td></tr>
</table>

the operations of the energy in the country and allow them to regulate themselves without government control, and at present the government is doing efforts to recuperate that control. But they don´t want to get control of generation only for the control through the regulations and laws. In this order, the government is defining an electricity supply Act with the collaboration of the technical assistance of the World Bank which it will have regulations for new energy development projects.)

- YK: requested access to the information of the NZ Company. JA answered that is not completed yet, but they expect to have it in 2 months and they are able to share it with us. The terms of reference will be shared.
- JA confirmed that NZ study is not including financial issues in this time.
- JA explained that for the 2nd survey program, JICA team has to take into account that rainy/hurricane season is from middle of May until November.

5. Presentation 2: **Financial Aspects in Geothermal Development** is presented and discussed . Following are some comments during the presentation.
   - Geothermal development could take up to 6 years or more, and this in the case that everything is moving in the good way.
   - Testing wells drilling has the highest risk in the project, and the investors are not willing to get involved in this stage of the project.
   - TK explained that, some years ago, GRENLEC presented a plan to install a 20 MW power plant for geothermal resource.
   - JA explained that the government plans to use geothermal electricity as a base load since the peak demand is 30MW.
6. Other discussions

Site Investigation

- ST asked if there is no problem to visit geothermal manifestations.
- CJ answered that JICA survey team may visit geothermal manifestations, however need to submit the work plan (sampling and shipping program) in ahead for permission from relevant departments such as Forest department. The work plan will be sent by JICA survey team later.
- CJ provided the information of a guide who has visited sites with the last JICA mission on November 2014 (guide: Mr. Telfor Bedeau, Hiking Guide, Tel. (473) 442 6200).

Information to be collected

- Information of Laws & Regulation can be obtained from web page of the government.
- TK asked if the existing two Acts (still in draft version) are enough for geothermal developments project by a PPP company. JA said that there is nothing approved to allow a PPP company to make investment on geothermal development projects.
- MT would like to have contacts with departments of environmental, forest, etc. in order to contact them directly. CJ promised to send her this information by e-mail.
- ST asked if we can contact the person in charge of the team from Jacobs (NZ Company)- JA said that there is no problem at all for that, and explained that this company is based in Saint Lucia island.
- CJ said that Ministry of Energy will not join the following meeting with GRENLEC in order not to disturb free discussion with them.

Wrap up Meeting

- Wrap-up meeting is set on 15 May at 13:00 with Ministry of Energy. Followed by the meeting with Permanent Secretary is set from 14:00

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

Minutes of Meeting (Memorandum within the JICA Team only)

<table>
<tr><td>Meeting</td><td>Grenada Electricity Services Limited (GRENLEC)</td><td>Venue</td><td>GRENLEC</td></tr>
<tr><td>Date</td><td colspan="3">2015/5/12 11:45-12:30</td></tr>
<tr><td>Participants</td><td colspan="3">[From Grenada side]
1. Mr. Murray Skeete (MS), Vice President- Engineering and Regulation, WRB (parent company of GRENLEC)
2. Mr. Collin Cover (CC), General manager and Chief Executive Office, GRENLEC
3. Mr. Clive Hosten (CH), Chief Engineer, GRENLEC
4. Mr. Ahmin Z. Baksh (AB), Planning and Engineering Manager, GRENLEC
5. Mr. Stanley Barreto (SB), Renewable Energy Developer, WRB
[From Japan side]
1. YAMAGUCHI Kazutoshi (YK), Latin America and the Caribbean Department, JICA
[JICA Survey Team]
1. TAKAHASHI Shinya (ST), Team Leader/ Geothermal Energy Development/ Reservoir Assessment
2. AKATSUKA Takashi (TA), Vice Team Leader/ Geology/ Drilling Planning
3. FUKUDA Daisuke (DF), Geochemistry
4. KAWASAKI Kiyoshi (KK), Geophysical Survey
5. KIKUKAWA Takeshi (TK), Electricity Policy/ Investment Policy
6. TERAMOTO Masako (MT), Environmental Social Consideration
7. Saul PADILLA (SP), Project coordination</td></tr>
<tr><td>Material</td><td colspan="3">No material used</td></tr>
<tr><td>Agenda</td><td colspan="3">1. Introduction of JICA survey team, purpose of survey
2. Interview and discussions on geothermal development status by GRENLEC</td></tr>
<tr><td>Discussions and Conclusions</td><td colspan="3">1. From Japan side
- YK introduced about JICA survey.
- ST explained the purpose of JICA survey as to examine the present situation of geothermal development in Grenada in order to propose the possible cooperation from Japan
2. From GRENLEC: MS from WRB, the parent company of GRENLEC, explained current situation most of the time during the meeting as follows.
[Policy for geothermal power generation]
- GRENLEC is interested in geothermal development at the stage of Power plant and Operation. Exploration and drilling in not within GRENLEC’s normal risk profile but it could potentially find joint venture partners to do this if necessary.
- Present maximum geothermal development is up to 10 - 15MW. Present minimum load is 17MW and the peak demand is 29MW.
- The financial source of the test drilling has not been decided. Resource exploration could be a task of the government.
- If the resource is proved, GRENLEC is ready to start business of geothermal with training for their staffs working for the diesel power plant now and hire new workers if needed.
- Regarding renewable energy, GRENLEC plans to introduce re-newables (wind, solar, geothermal or other) for 20% of their power generation by 2020.
[Organization and business]
- In Grenada, GRENLEC is the only power company who can be a power operator by law.
- WRB has 50% of share, while the government has 10%, citizens and employees have ~29% and the National Insurance Scheme has the rest ~11%
- Tariff is also registered in the law.
3. Others
- Next meeting is set on 13 May at 14:30. Several options on geothermal business model and financial scheme would be proposed by JICA Survey Team for further discussion.</td></tr>
<tr><td>Photo</td><td>
From L to R: CH, AB, CC</td><td colspan="2">
From L to R: SB, MS</td></tr>
</table>

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

Minutes of Meeting (Memorandum within the JICA Team)

Meeting	Grenada Electricity Services Limited (GRENLEC)	Venue	GRENLEC
Date	2015/5/13 14:30-15:30		
Participants	[From Grenada side] 1. Mr. Murray Skeete (MS), Vice President- Engineering and Regulation, WRB (parent company of GRENLEC) 2. Mr. Robert Blanchard, Jr. (RB1), President, WRB 3. Mr. Robert Blenker (RB2), Vice President –Renewable Energy, WRB 4. Mr. Collin Cover (CC), General manager and Chief Executive Office, GRENLEC 5. Mr. Clive Hosten (CH), Chief Engineer, GRENLEC 6. Mr. Ahmin Z. Baksh (AB), Planning and Engineering Manager, GRENLEC [From Japan side] 1. YAMAGUCHI Kazutoshi (YK), Latin America and the Caribbean Department, JICA [JICA Survey Team] 1. TAKAHASHI Shinya (ST), Team Leader/ Geothermal Energy Development/ Reservoir Assessment 2. KIKUKAWA Takeshi (TK), Electricity Policy/ Investment Policy		
Material	No material used		
Agenda	1. Interview and discussions on geothermal development status by GRENLEC 2. Interview and discussions on draft electricity supply bill		
Discussions and Conclusions	1. From Japan side - TK asked the readiness of the draft geothermal development bill and the GRENLEC's position for risk/profit sharing with the steam production. - TK also asked the prospect of the possible agreement on the different views on the draft electricity supply bill between GRENLEC and the government. 2. From GRENLEC: MS and RB2 explained the current situation on the draft bills. [Draft geothermal development bill] - GRENLEC collaborated with the government in drafting the bill. The draft bill took into considerations the good practice in other countries and the local context of Grenada. Hence the bill has been well drafted. - However due to the election and the change of the ruling party, the bill has not been approved in the Parliament. - One of the major topics is the issue of the property right of geothermal resources. The draft bill stipulates the resources belongs to the State. The government will then give approval for the use of the resources to the operator. - Geothermal plants could be developed by GRENLEC with the current legal and legislation if the property rights issue is resolved among the stakeholders. [Draft electricity supply bill] - Grenlec hopes to find the mutual agreements on the argument points. Grenlec believes it achieves high efficiency of the management and operation of the company, providing a competitive electricity price. - There are a few countries in the Caribbean region where IPPs operate such as Jamaica, Trinidad, and Antigua. - The new electricity bill has no impacts on the geothermal development. Even if the discussions on the draft bill are not settled, the current legal framework would support the investment activities. [Geothermal development] - Grenlec wishes to collaborate with potential partners (steam provider) in geothermal development. 3. Others - n/a		
Photo	n/a		

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

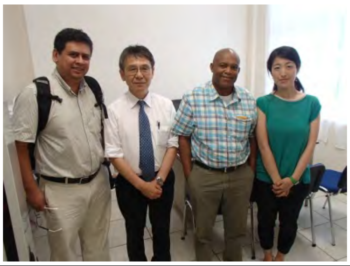
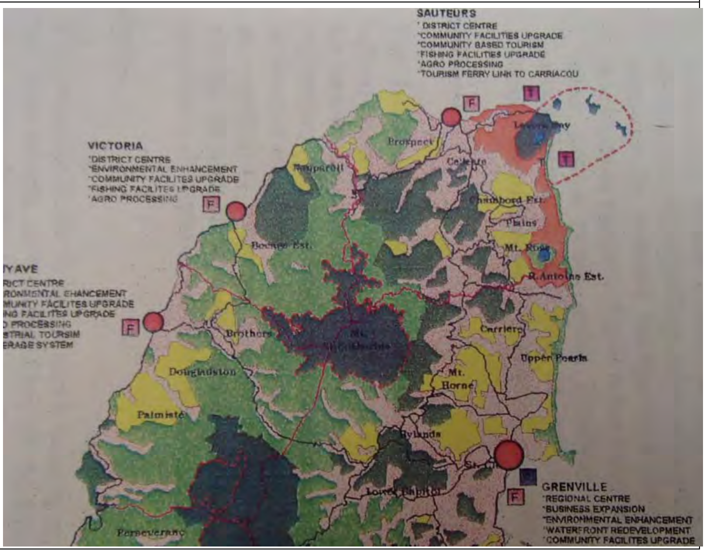
Minutes of Meeting

<table>
<tr><td>Meeting</td><td>Meeting with Ministry of Finance and Energy, Office of Permanent Secretary</td><td>Venue</td><td>Financial Complex</td></tr>
<tr><td>Date</td><td colspan="3">2015/5/15 9:15-10:00</td></tr>
<tr><td>Participants</td><td colspan="3">[From Grenada side]
1. Timothy N. J. Antoine (TA), Permanent Secretary
2. Mr. John Auguste (JA), Senior Energy Officer, Ministry of Finance and Energy
3. Mr. Christopher Joseph (CJ), Energy Officer, Ministry of Finance and Energy
[From Japan side]
1. YAMAGUCHI Kazutoshi (YK), Latin America and the Caribbean Department, JICA
[JICA Survey Team]
1. TAKAHASHI Shinya (ST), Team Leader/ Geothermal Energy Development/ Reservoir Assessment
2. AKATSUKA Takashi (TA), Vice Team Leader/ Geology/ Drilling Planning
3. FUKUDA Daisuke (DF), Geochemistry
4. KAWASAKI Kiyoshi (KK), Geophysical Survey
5. KIKUKAWA Takeshi (TK), Electricity Policy/ Investment Policy
6. TERAMOTO Masako (MT), Environmental Social Consideration
7. Saul PADILLA (SP), Project coordination</td></tr>
<tr><td>Material</td><td colspan="3">1. Inception Report
2. PPT presentation on Overview of Geothermal Development and Queries</td></tr>
<tr><td>Agenda</td><td colspan="3">1. Opening speech from Mr. Yamaguchi
2. Welcome from Permanent Secretary
3. Explanation of JICA survey from Mr. Takahashi</td></tr>
<tr><td>Record of Meeting</td><td colspan="3">1. From Permanent Secretary
- TA: welcome the JICA survey team and thanks for the interest to help to Grenada to develop the geothermal resource.
2. From JICA
- YK: Thanks to the Permanent Secretary for the time and allow us to explain the objectives of the mission. And explained that this mission is in coordination with IDB and CDB.
3. From Japan side
- ST: Introduced the team members participating in the survey during this week, including Mr. Yamaguchi as the responsible of JICA for the Caribbean countries.
- ST: gave an inception report to TA which was presented to JA and CJ at kick-off on 12 May.
- ST: explained the objective of JICA Survey as to collect and review existing data and information regarding geothermal development in Grenada, to conduct field surface survey if necessary, and to identify geothermal development project/s which JICA could extend its assistance through the international partnership.
Things to be clarified in the 1st survey are:
(1) What kind of cooperation could be implemented by JICA without duplication between NZ's study?
(2) To whom JICA would assist regarding technical and financial cooperation, GRENLEC or Ministry?
(3) Implementation framework of geothermal project is not yet clearly identified.
- TA: clarified that GRENLEC is not a leader of future geothermal development in Grenada the government of Grenada is the one. Only after the potential is demonstrated, GRENLEC can be one of the potential investors that could be interested in the development. It is not appropriate to lead the discussion with GRENLEC.
- TA: explained that they are working for drafting legal framework and legislation for geothermal development with GRENLEC as a key partner. Not yet received it but will be ready in the later this year. This is potentially one of the areas that Japan can help Grenada to finalize geothermal legislation. Draft of geothermal legislation will be shared with JICA team. And you are welcome to comment on it.
- TA: explained that the Government of Grenada wants the shortest possible period of development and followings actions are to be done for it.
(1) Establish liability.
(2) Prepare Electricity Supply Act.</td></tr>
</table>

	(3) Prepare Geothermal Development Act. (4) Convene the partners. (5) Fund to prove geothermal resource to call investors. - ST: asked what is following with the NZ Company. Because this is not clear at moment. - TA: answered that it is not clear about NZ further study, probably no other participation to continue with the project. It is an opportunity for Japan to take us forward by examining the possible test drilling sites. - TA: Mentioned that he consider that Japan can collaborate with the government of Grenada to establishment of Laws and Regulations of geothermal developments in Grenada as well as technical assistance and human resource development. - TK: asked about financial and business matter. What would be the government's role? - TA: explained that government's role is establishing legal framework. Once resource is proven by grant, private partners involve in project. - MT: For next stage of test drilling, necessary EIA study should be prepared. If NZ's study doesn't include EISA, JICA study could assist it. End of discussion.
Photo	

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

Minutes of Meeting(Internal use only within the JICA Team)

Meeting	Meeting with Physical Planning Unit,	Venue	GCNA Complex Building
Date	2015/5/15 14:30-15:30		
Participants	[From Grenada side] 1. Mr. Fabian Purcell (FP), Head{Ag}, Physical Planning Unit, Ministry of Works, Physical Development and Public Utilities [JICA Survey Team] 1. TAKAHASHI Shinya (ST), Team Leader/ Geothermal Energy Development/ Reservoir Assessment 2. TERAMOTO Masako (MT), Environmental Social Consideration 3. Saul PADILLA (SP), Project coordination		
Material	N/A		
Agenda	1. Interview on EIA in Grenada		
Record of Meeting	1. JICA survey team explained about JICA study and status of our cooperation on geothermal development in Grenada 2. FP asked about the geothermal power plant facilities and possible environmental influence by geothermal development. Impacts on water and plants should be carefully determined because agriculture is important industry in Grenada. 3. Following information was given to JICA study team. - There is no regulation or guideline about EIA in Grenada. Need to refer to best practices of other countries or international agencies. - The water and sewage company is the only responsible to drill water wells for human consumption. To do it, they are required to present the project to this office and they can proceed to drill. - Mitigation measures should be prepared for both preparatory works and drilling works. - The team explained that the required area for a drilling site is like a yard for football, approximately. - The potential sites around Mt. St. Catherine are possibly inside “Conservation Area”. ⇒Necessary to check the position of potential sites with the map below - However, FP talked that the development might be possible because renewable energy is a policy of government of Grenada. ⇒Need to be clarified with relevant organizations (Ministry of forestry)		
Photo			
			

Comments of JICA study team:

During 2nd survey, it might be a good idea to have a workshop for relevant organizations to deepen their understandings of geothermal development project.
Possible stakeholders are Ministry of energy, Ministry of Forestry, Ministry of physical planning and Ministry of tourism.

グレナダ地熱開発にかかる情報収集確認調査
フォーラム議事

<u>第一日目：Ministerial Forum</u>

日時：2016 年 6 月 21 日（火）9:00-15:00
対象：グレナダ国関連役所職員
参加者役所関連：約 20 人（Physical Planning Unit, Min.of Agriculture, Works Finance 等）
エナジーユニット：2 人
NZ(Jacobs)：1 人
JICA　Team:　3 人（赤塚、菊川、寺本）

主な質問：

- 電気料金は安くなるのか？どのくらい？
- GRENLEC と発電会社の PPA に政府はどのように関与するのか？
- 政府への無償資金はコストして計上しなければいけないのではないか。
- Contingent Grant の場合の計算はしていないのか？
- 組織体制は？
  - Gethermal Unit を設置し関係政府組織と連携をとる必要性がある（Energy Unit）。
- 水源の水質への影響は？
  - 影響が出ないように ESIA でアセスメントをする。Nawasa, Forestry と十分にコミュニケーションをとりながら掘削水の取水計画を策定する必要がある（調査団）。

主なコメント：

- キャサリン山は Flora（様々な植物相？）の生息域である。
  - このため、Biodiversity の調査は必須である（調査団）。

政府職員は発電プロジェクトの経験もないため、専門的な質問や答えに窮するものはなかった。

以上

<u>第二日目：Stakeholders' Meeting</u>

日時 2016 年 6 月 23 日（木）9:00-12:00
対象者：ステークホールダー（地元関係者、NGO、IPP）
エナジーユニット：１人
NZ(Jacobs)：1 人
JICA　ドミニカ共和国事務所：森田
JICA　Team:　4 人（高橋、赤塚、菊川、寺本）

主な質問：

- キャサリン山はグレナダ国の貴重な森林である。水、森林、生物の他、地元民への配慮等を忘れてはならない。
- 広く、パブリックミーティングを行い、コンセンサスを得る必要がある。
- 代替案は検討したのか、太陽光、風力、潮力など。エネルギーミックスは考えているのか。
- 地熱発電のアフォーダビリティーも検討する必要がある。
- 運転計画は何年か？15 UScent/kwh の価格が保てるのか？？？？？
- 15 UScent/kwh の価格に政府へのロイヤリティーが含まれているのか。
- ESIA のタイミングは（特に掘削との時間的関係）？
  - 少なくとも試掘前、および生産井掘削と建設前の 2 回は必要（調査団）。

主なコメント：

- （掘削用水について）ton で言われても、イメージしにくい。

GRENLEC からの参加者以外は、一般の方々なので、自然社会環境への影響に大きな関心を示した。地熱以外の再生可能エネルギーへの関心もあった。
GRENLEC からの参加者はもっぱら価格に関心があるようであった。

以上

<u>第三日目：Partners' Forum</u>

日時：2016 年 6 月 24 日（金）8:30-15:00
対象：開発パートナー（主に国際協力機関）
主な参加者：NZ 大使、CDB、DFID、US 大使館、EU 代表者、カリコム事務局
グレナダ政府：総理大臣（冒頭挨拶）、財務省国際協力担当次官
エナジーユニット：2 人
NZ(Jacobs)：1 人
JICA　ドミニカ共和国事務所：森田
JICA　Team:　4 人（高橋、赤塚、菊川、寺本）

主な発言内容：

１．　今後の事業の推進には ESIA が重要である。工事用水、廃棄物処理などアセスする必要がある。

２．　CDB は IDB 融資の SEF（sustainable energy fund）total 71.5 million USD がある。
　① Global Credit Loan (GCL):　20 million
　② Clean Technology Fund　(Grant): 19 million
　③ Global Environment Facility Trust Fund (Grant): 3 million
　④ Counterpart contribution: 29.4 million
　グレナダ用のグラント枠があり、試掘に利用できる可能性がある。

３．　NZ は、次のステージに技術支援（T/A）を続けていく準備がある。プロジェクトマネージメント、技術管理、NZ でのトレーニング等である。マスターコース（奨学金制度）もある。

４．　DFID は、CDB に UK Caribbean Infrastructure Fund（23Million ポンド）を提供している。地熱は 4 カ国が対象である。試掘にも活用できる。SVG では、試掘資金を提供している。

５．　IDB の資金は、グラント試掘には不適切である。Contingent-recovery resources, GeoSmart Facility (SEF の財源)等があるが、次のステージから活用できる。

６．　JICA は、CDB と資金支援のネゴ中である。ただし、グラントではなくローンである。

７．　カリコム事務局：他にアブダビファンドなどもありセントルシアや SVG の投入されている。情報の共有が大切である。

主な質問：

- Florida では（掘削用の）水が少ないのではないか？
  - 最寄りの河川で NAWASA の施設の下流で選定したが、その他のリソースについても詳細掘削計画時に検討したい（調査団）。
- 掘削泥水の処理はどうするのか？
  - 通常、汚染物質が含まれないため、スラッジは乾燥させ、当該国の法に従い最終処分をするものと考える（バルバドスに搬送などは不要と思われる）（調査団）。
- グレナダにおける地熱発電の位置づけ？ソーラー等は検討しないのか。
  - プロジェクト側は、グ国において地熱発電について詳しい人はほとんどいないという認識が必要。
  - 今後、ステークホルダーへの説明の際には、他の再生可能エネルギーと地熱との相違（ベースロードになる）や、グ国の地熱ポテンシャルについて、基礎から説明が必要だと考えられる。

以上

<u>追加：Stakeholders' Meeting</u>
日時：2016 年 6 月 28 日（火）9:00-12:00
上記第二日目のステークホールダー会議に、重要な NGO が参加していないので、追加日程が組まれた。
主な参加者：NGO、ローカルディベロッパー合計 9 人
エナジーユニット：1 人
NZ: 1 人
JICA　調査団：1 人（高橋）

主な質問と指摘事項は以下の通りであった。
- キャサリン火山が噴火する可能性はないのか（地熱開発とは関係なく、一般的に）
- 環境や地域住民への影響を検討する必要がある。
- プロジェクト地域の地域住民の活用が重要である。雇用やローカル知識を活用すべきである。
- 地熱は、新しい話題である。生態系や水系などにセンシティブである。
- キャサリン火山は、グレナダの貴重な水源涵養地帯であり、神聖な森である。2010 に水が枯渇した事件があった。十分に注意する必要がある。生物多様性も検討する必要がある。キーステークホールダーは、農民である。
- 土地使用や住民雇用、教育訓練なども検討する必要がある。
- 風力や太陽光などとのコスト比較は実施したのか。なぜ地熱なのか、他の代替案も検討する必要があるのではないか。
- 掘削地点を示すマップに保護地区のゾーニングがあったが、これらを含めて第 3 者がアセスする必要があるのではないか。

話題は主に環境問題に集中した。これに対して、
- 今回は地熱資源の有無を検討した段階であり、環境アセスは予備的なスコーピングを行ったものである。
- 実際の試掘前には、国際基準に従って ESIA を実施され、ステークホールダー会議も開かれる。
- 調査結果は、一般に公開されてコメントを求める手順が踏まれることになる。

等を説明して閉会した。

以上

添付資料-2　　現地写真

Appendix-2 Record Photographs

	
Hot Spring and Alteration (Hapsack)	Hot Spring (Chambord, Sulfur Springs)
	
Hot Spring (Peggy's Whim)	Hot Spring (Clabony)
	
Hot spring (Castle Hill South)	Travertine consist of Carbonate Mineral (Castle Hill South)

Main Road in the City of Grenville

Main Road in the Gouyabe

Eastern Coastal Road

Access Road on the vicinity of the Drilling Site

Paradise Bridge

Belmont Blidge

Overview of Grand Etang Lake

Antonie Crater

Transmission Line

St. Georges Port

Queen’s Park Power Station

Small Power Station in Grenada University

Meeting with Ministry of Finance, Energy Unit

Meeting with Grenlec

Overview of St. George's Town

Building of Ministry of Finance, Energy Unit

Old Airport

Gravity Survey (Gravimeter and GPS)

添付資料-3　プレゼンテーション資料

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

INCEPTION PRESENTATION

MAY 2015
In St. Georges

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

OUR TEAM

TAKAHASHI Shinya	Team Leader/ Geothermal Energy Development/ Reservoir Assessment
AKATSUKA Takashi	Vice Team Leader/ Geology/ Drilling Planning
FUKUDA Daisuke	Geochemistry
KAWASAKI Kiyoshi	Geophysical Survey
TERAMOTO Masako	Environmental Social Consideration
KIKUKAWA Takeshi	Electricity Policy/ Investment Policy
MOMOSE Yasushi/ YOSHIDA Satoshi	Civil Engineering Planning

NK: Nippon Koei Co., Ltd.

Geo-E: JMC Goethermal Engineering Co., Ltd.

SRED: Sumiko Resource Exploration and Development Co., Ltd.,

BACKGROUND: International Partnership

1. IDB and JICA entered in the agreement on "Cofinancing for Renewable Energy and Energy Efficiency (CORE scheme)" in 2013,
2. IDB, JICA and CDB entered in the Memorandum aiming at building a new partnership to promote renewable energy and energy efficiency in Eastern Caribbean Region in 2014.

BACKGROUND: Project Identification by JICA

1. JICA conducted a preliminary survey in 12 CARICOM countries to identify projects regarding renewable energy and energy conservation in 2014;
2. Grenada has been identified as one of the potential countries for geothermal development.

OBJECTIVES

1. To collect and review existing data and information regarding geothermal development;
2. To conduct field surface survey if necessary;
3. Thereby, to identify geothermal development project/s which JICA could extend its assistance through the international partnership;

➔ Based on the above, another JICA Survey may be implemented to formulate specific cooperation programs for geothermal development.

PRESENT SITUATIONS - OUR UNDERSTANDINGS

1. Six geothermal prospects have been identified in early 1990's.
2. Geothermal Support Partnership Framework Agreement between the government of Grenada and New Zealand was agreed in 2014.
3. Geological, geochemical and geophysical survey is being conducted by an eminent New Zealand Consultants.
4. GRENLEC (a private owns 50% stocks) is only operator of electric sector.
5. Implementation framework is yet to be decided (i.e. implementation organization, financial arrangement and etc)

OUR ACTIVITIES (for 1st visit)

1. To collect relevant data and information; a questionnaire has already been sent to the Energy Office;
   the information includes the survey plan and results of the NZ consultants;
2. To conduct field survey if judged necessary and approved;
3. To discuss implementation framework, financial arrangement and others as necessary for geothermal development ;
4. To have a wrap up meeting on 15th May 2015.

Schedule for the 1st Visit

May, 2015		Team Leader	Development/Investment	Geology/Drilling	Geo-chemist	Environment	Geo-physics	Coordination	Civil Eng.
9	Sat		Arriving						
10	Sun	Arr.	Preparation						
11	Mon	Kick-off meeting							
12	Tue	Discussions with relevant organization							
13	Wed	Data Collection							
14	Thu	Data Collection							
15	Fri	Wrap-up Meeting							
16	Sat	Moving							

Surveys to be conducted for the 2nd visit, if judged necessary

1. Analysis of remote sensing data,
2. Geological field survey and laboratory analysis,
3. Geochemical field survey and laboratory analysis,
4. Geophysical field survey and/or 2-D inversion analysis,
5. Scoping for Environmental and Social Impact Assessment (ESIA), Gap analysis of guidelines for ESIA
6. Survey and analysis on electricity policy and investment policy
7. Others as necessary

NIPPON KOEI Geo-E

Overall schedule

No.	Position	Name	2015: 3	4	5	6	7	8	9	10	11	12	2016: 1	2	3
1	Team Leader/Geothermal Development Plan/Reservoir	Shinya TAKAHASHI			■	▪	▪	▪	▪	▪	▪	▪		■	
2	Sub-Team Leader/Geology/Drilling Engineer	Takashi AKATSUKA			■	▪	▪	▪	▪	▪	▪	▪		■	
3	Geochemistry	Daisuke FUKUDA			■	▪	▪	▪	▪	▪	▪	▪			
4	Geophysics	Kiyoshi KAWASAKI			■	▪	▪	▪	▪	▪	▪	▪			
5	Environmental and Social Considerations Evaluation	Masako TERAMOTO			■	▪	▪	▪	▪	▪	▪	▪			
6	Energy Policy Analysis/Project Finance Policy Analysis	Takeshi KIKUKAWA			■	▪	▪	▪	▪	▪	▪	▪		■	
7	Civil Engineering Planning	Yasushi MOMOSE/ Satoshi YOSHIDA			■	▪	▪	▪	▪	▪	▪	▪			
Report				△ IC/R			△ PR							△ DF/R	△ F/R

*Intermittent: Detailed survey plan will be made after the discussion.
IC/R: Inception Report, P/R: Progress Report, DF/R: Draft Final Report, F/R: Final Report

NIPPON KOEI Geo-E

Deliverables

1. Inception Report: May, 2015
2. Progress Report: August 2015
3. Draft Final Report: February 2016
4. Final Report: March 2016

NIPPON KOEI Geo-E

Remarks

- This JICA survey will be conducted in close communication with IDB and CDB, for possible cooperation in geothermal energy development in Grenada.

NIPPON KOEI Geo-E

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

We appreciate
your understanding and cooperation

Thank you
Arigatou

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT

Financial Aspect in Geothermal Development

GRENADA

MAY 2015

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Today's Presentation

Part-I: Overview of Geothermal Project Risk

Part-II: Finance Options for Geothermal Development

Information provided in the presentation is not confidential but quoted from the public domain in order to provide related references for the counterpart organizations.
In addition, the presentation by the JICA Survey Team does not represent nor endorse the policy and viewpoints by the donor agencies.

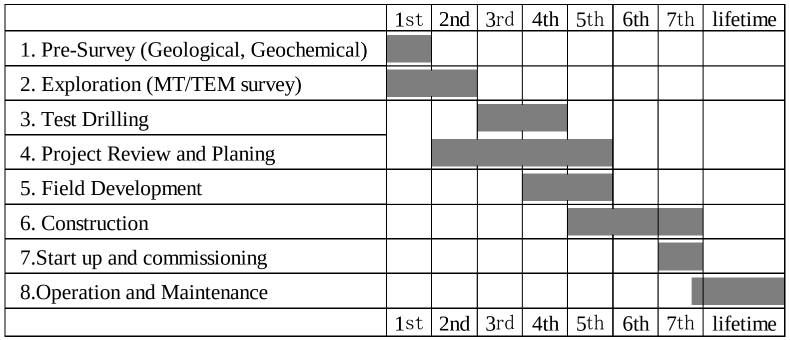
PART-I

- Overview of Geothermal Project Risk

1. Geothermal Project Development Schedule
2. Geothermal Project Risk Identification
3. Project stage and Project Risks
4. Experiences in the World

Geothermal Project Development

(for a Unit of Approximately 50 MW)



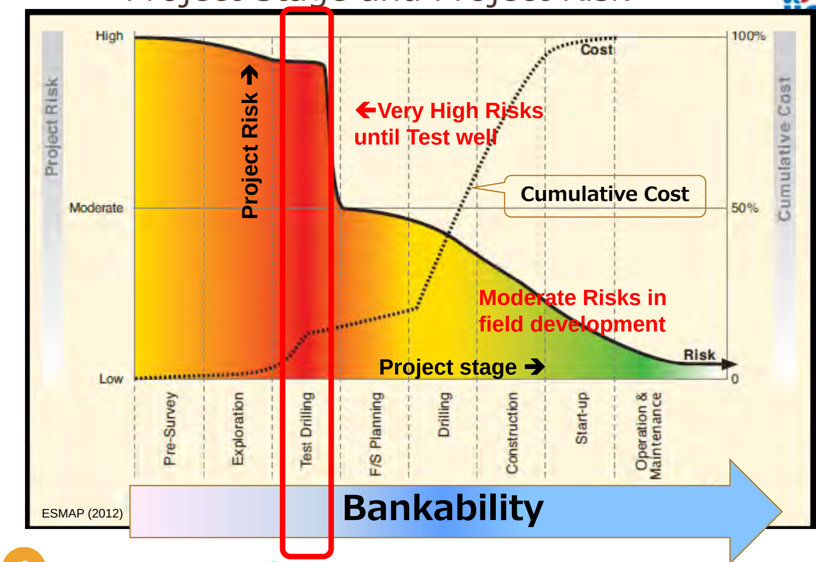
ESMAP 2012

It needs approximately six years to a start up and commissioning.

Geothermal Project Risk Identification

1. **Financing Risks**, due to a High Upfront Cost and a Long Lead Time
2. Resource or Exploration Risks
3. Completion or Delay Risks (due to difficult geology)
4. Risk of Over-sizing the Power Plant (due to resource over estimation),
5. Operation Risks (due to steam field operation and maintenance)
6. Off-take Risk and Price Risk
7. Regulatory Risk

Project Stage and Project Risk



Experiences in the World

Project stages

	1 Preliminary Survey	2 Surface Exploration	3 Test Drilling, F/S	4 Field Development	5 Power Plant Construction	6 O&M	Note
	Early Stage			Middle Stage	Late Stage		
1	A Fully integrated single national public entity			Public Entities			Kenya (Olkaria), Costa Rica, Indonesia (before), NZ
2	Multi national public entities (Early stage by one entity and subsequent stage by other/s for an example)						
2'	Public entity (CFE)				Private Contractor	CFE	Mexico (OPF model)
3	National and municipal public entities						**Iceland (before)**
4	Fully integrated JV partially owned by the government						El Salvador (LaGeo + Enel Green Power), Japan(recent)
5	Public entities			Private Developers			**Japan (before)**
5'	Public entity (PNOC EDC)				Private Developer	NPC	Philippines BOT model;
5"	Public entities (GDC in Kenya, Purutamina in Indonesia)				Public entities (Steam production) / Private Developers (power generation)		**Kenya (KenGen + GDC), Indonesia (before), Philippines (before)**
6	Public entities			Private Developers			**US, Turkey, NZ, Guatemala, others**
7	Public entities		Private Developers				**US, Nicaragua, new Chile**
8	Private Developers			Private Developers			**New Philippines, New Indonesia, Italy, others**

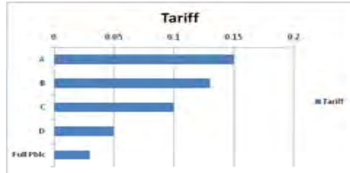
ICE: Instituto Costarricense de Electricidad, Costa Rica; CFE: Federal Commission for Energy, Mexico; PNOC EDC: Philippines National Oil Co.,-Energy Development Corporation, Philippines; NPC: National Power Corporation, Philippines; GDC: Geothermal Development Company, Kenya;

(Original Source: ESMAP 2012, modified by JICA Team)

Business model & Tariff Level (an example)

Business Model	Preliminary Survey	Exploration	Test drilling	F/S & planning	Field development	Plant construction	Operation: Field	Operation: Plant	Tariff ($/kWh)	Remarks
A	Public	Private							0.15	
B	Public		Private						0.13	
C	Public			Private					0.10	
D	Public					Private	Public	Private	0.05	
Full Public	Public								0.03	

(Source: JICA Team)



PART-II

Financial Options for Geothermal Development

1. Options for Financial Arrangement
2. Capital Structure vs. Success of Project
3. JICA Projects
   in Indonesia, in Bolivia, in Costa Rica
4. IDB Facility for Geothermal Development
5. Loan Guarantee by IFC
6. Geothermal Development Facility (GDF)

Options for Financial Arrangement

Arrangement for Implementing Organization -Options from viewpoints of financial arrangement-

Possible Options	Development Stage					
	Preliminary Survey	Surface Exploration	Test Drilling	Field Development	Power Plant Construction	O&M
Option-1	PPP	PPP	PPP	PPP	PPP	PPP
Option-2	GRENLEC	PPP	PPP	PPP	PPP	PPP
Option-3	GRENLEC	GRENLEC	PPP	PPP	PPP	PPP
Option-4	GRENLEC	GRENLEC	GRENLEC	PPP	PPP	PPP
Option-4	GRENLEC	GRENLEC	GRENLEC	GRENLEC	PPP	PPP
Option-5	GRENLEC	GRENLEC	GRENLEC	GRENLEC	GRENLEC	PPP
Option-7	GRENLEC	GRENLEC	GRENLEC	GRENLEC	GRENLEC	GRENLEC

note) PPP: Public Private Partnership

Possible Financing Sources for Development

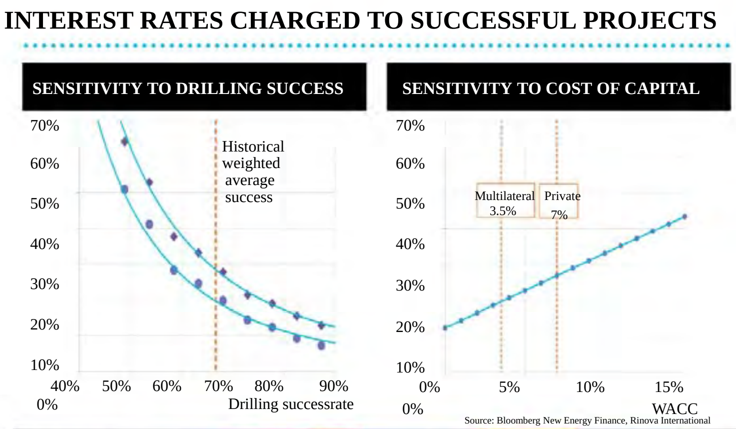
Possible Financing Sources	Development Stage					
	Preliminary Survey	Surface Exploration	Test Drilling	Field Development	Power Plant Construction	O&M
Government Budget	To be discussed in the Study. Depending on (i) project characteristics, (ii) government policy, (iii) organizational arrangement, and (iv) availabilityand condition of finance.					
Guarantee Scheme (e.g. IDB Facility)						
Concessional Loan (e.g. ODA)						
Commercial Loan						

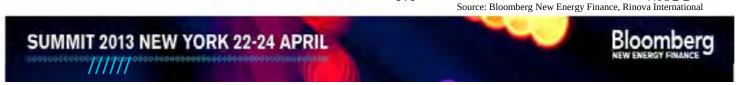
Risk Management and Financial Facility

	Iceland	Indonesia	Japan	Mexico	New Zealand	Philippines	Turkey	USA
Drilling Failure Insurance							X	
Government-led Exploration	X	X	X	X	X	X	X	
Cooperative Agreements								X
Grants	X		X					
Lending Support Mechanism		X						X
Loan Guarantees								X

Source) Geothermal Development Workshop, IFC (2014)

Capital Structure vs. Success of Project





Source) Bloomberg New Energy Finance

JICA Project in Indonesia

Engineering Services for Kamojang Geothermal Power Plant Extension Project

1. Overview

The Project aims to develop the geothermal power plant (60MW). The loan is allocated for the engineering services for design and the test drilling.

2. Loan

Amount;	JPY 995 mil.
Interest Rate;	1.5%
Amortization;	30 years
Grace Period;	10 years

3. Implementing Agency

PT PLN (Persero) (state-owned power utility)

JICA Project in Bolivia

Laguna Colorada Geothermal Power Plant Project (1st Phase)

1. Overview

The Project aims to develop the geothermal power plant (50MW), the transmission line and the substation . The loan is allocated for the engineering services for design and the field development.

2. Loan

Amount;	JPY 2,495 mil.
Interest Rate;	Main Work 0.65%, Engineering Services; 0.01%
Amortization;	40 years
Grace Period;	10 years

3. Implementing Agency

Empresa Nacional de Electricidad (state-owned power utility)

JICA Project In Costa Rica

Guana Caste Geothermal Development Sector Loan

1. Overview

The Project aims to develop the multiple geothermal power plants. The loan is allocated for the engineering services for design, the field development, and the civil works for power plants.

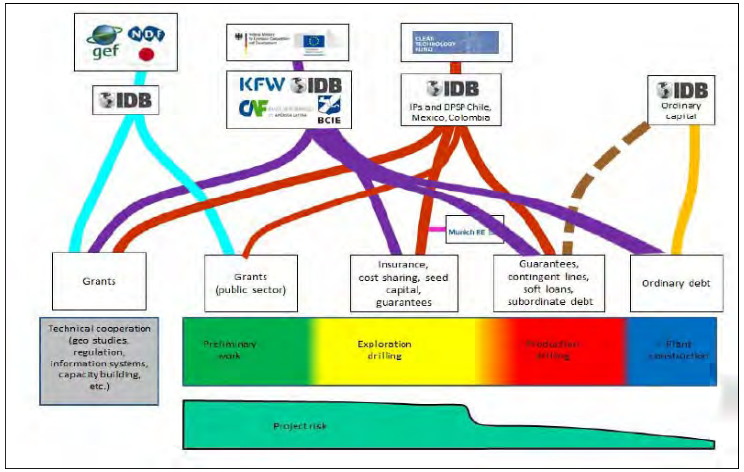
2. Loan

Amount;	JPY 16,810 mil.
Interest Rate;	Main Work 0.60%, Engineering Services; 0.01%
Amortization;	40 years
Grace Period;	10 years

3. Implementing Agency

Instituto Costarricense de Electricidad (state-owned power utility)

IDB Facility for Geothermal Development



Source) IDB Web Data

IDB Facility for Geothermal Development

1. Grants to finance technical assistance

   (e.g. Prefeasibility studies, such as surface studies, hydro-chemical and hydrogeological studies, electromagnetic studies, modeling , Design of Public Private Partnership (PPP) schemes)

2. Direct loans to governments of the Region

   (for developing geothermal projects, through public utilities or private players)

3. Corporate or project finance to private developers

   (For projects in advanced phases, IDB can provide a range of financial instruments for late stage exploration, production wells and cost overruns.)

4. Lines of credit to development banks to provide geothermal financing to developers

   (During each and every stage of a geothermal project, the IDB facilitates the provision of structured finance tailored to each project, seeking to provide flexible financing terms aligned to the expected cash flow of the project.)

5. Access to international concessional finance

(Opportunity to offer risk mitigation instruments such as loans convertible to grants, insured loans, cost-sharing schemes for the early exploration phase, loan guarantees, or insurance premiums.)

Loan Guarantee by IFC

<Overview>

- National government underwrites loan taken on by developer
- Allows developer to access debt
- Government repays to bank in case of failure
- Developer pays fee for guarantee
- Impact on tariff

<Pros>

- Simple to structure/ administer through national development bank
- Project risk lower
- Can be a self-sustained fund

<Cons>

- Impact on government balance sheet
- Possible limits for guarantee

Geothermal Development Facility (GDF)

The GDF constitutes the first multi-donor initiative to promote geothermal energy on a continental scale. It will provide at least USD 75 million in grant-based risk mitigation instruments and USD 1 billion in tailored financing to geothermal projects in a range of Latin American countries

- The GDF seeks to incentivize at least 350 MW of geothermal generation capacity.
- Under the Risk Mitigation Fund public and private developers will be able to apply from early 2016 onwards for a Contingency Grant that will cover up to 40% of the cost of up to three early exploration wells.
- Grants received will only have to be repaid in case of a successful exploration.
- Developers will further be able to refinance grant repayments through the provided Bridge and Investment Financing Lines for geothermal power plants.

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN

Thank you
Arigatou

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT IN GRENADA

Overview of Geothermal Development

MAY 2015

In St. Georges

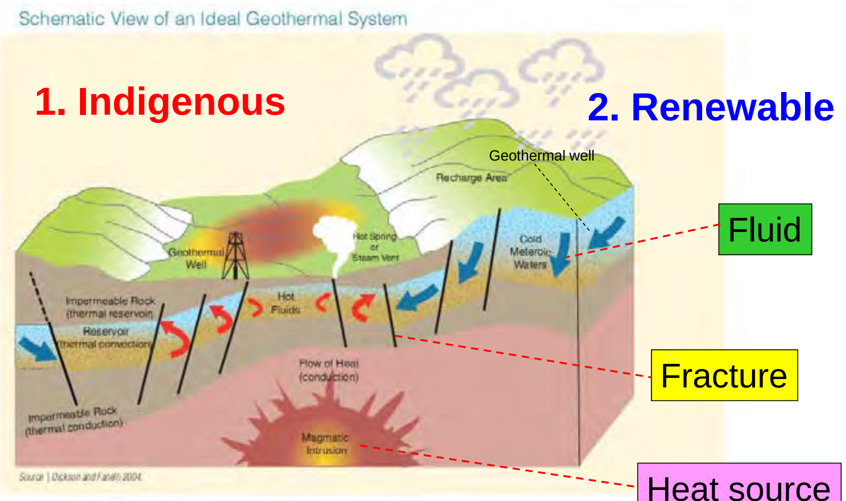
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Introduction of Geothermal Power Generation

Superiority of Geothermal Power Generation

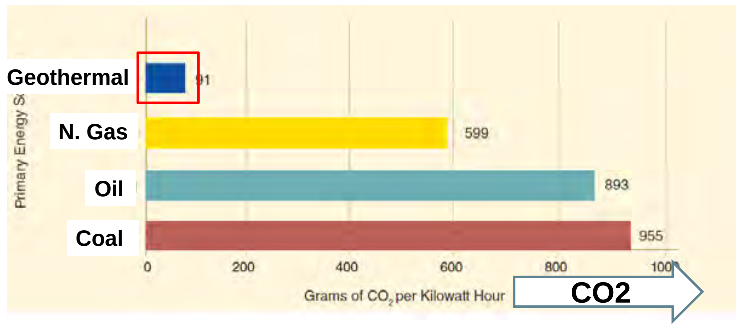
Two Key Characteristics



- USGS on www.cnsm.csulb.edu
- Industry professionals often use the terms "high-enthalpy" and "high-temperature" as synonyms when describing geothermal resources (Eliasson 2001). Enthalpy is a measure of the total energy of a thermodynamic system including the latent heat of vaporation/condensation. As such, it more accurately describes the energy production potential of a geothermal system that includes both hot water and steam.

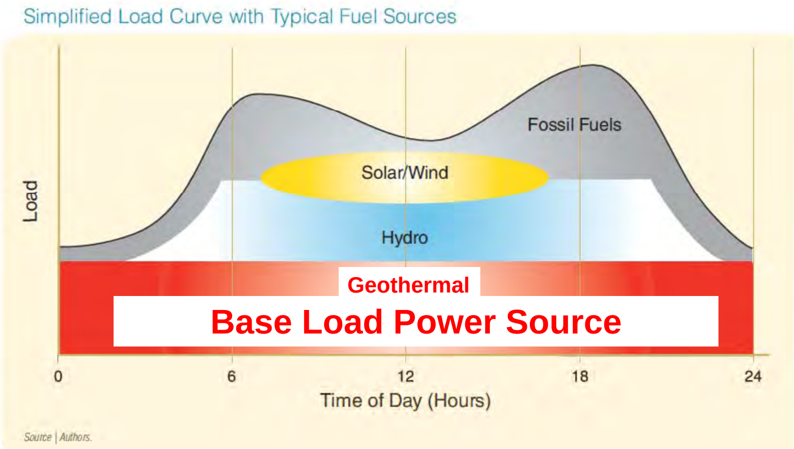
Other Salient Characteristics

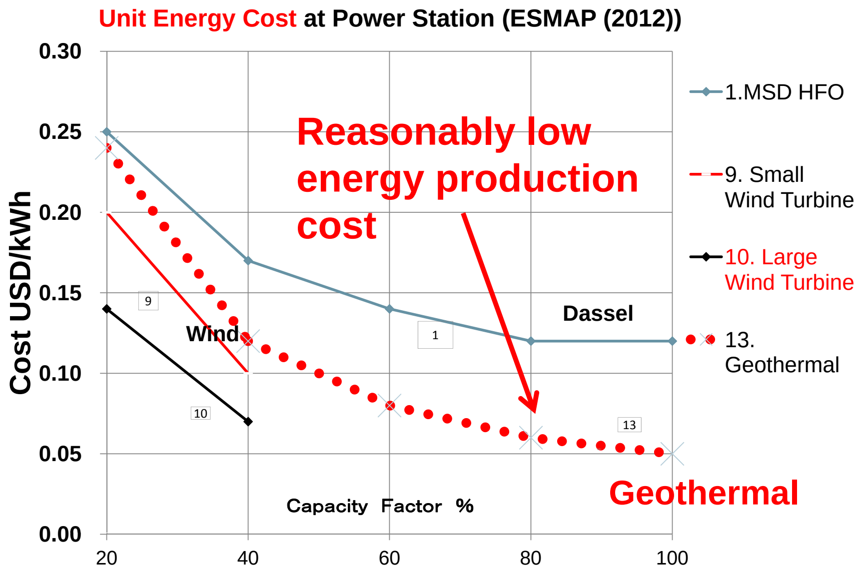
1. Low CO_2 Emission



2. High capacity factor : more than 70%
(Compare with Wind: 20%, Solar: 12%)

Contribution to the power supply as:

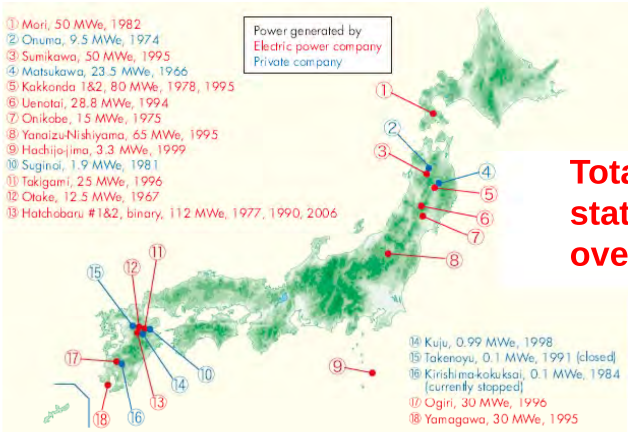




Geothermal Power Plant in Japan

Geothermal Power Plants in Japan

The first installation at Matsukawa in 1966, being operational for 50 years.



Total 18 power stations, over 500 MWe

Geothermal Turbine:

The most important facility for Geothermal power generation

Geothermal turbine manufacturer

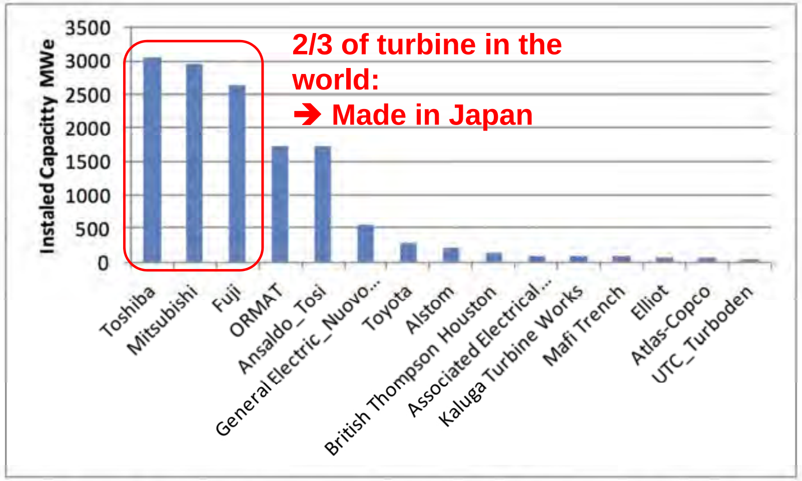
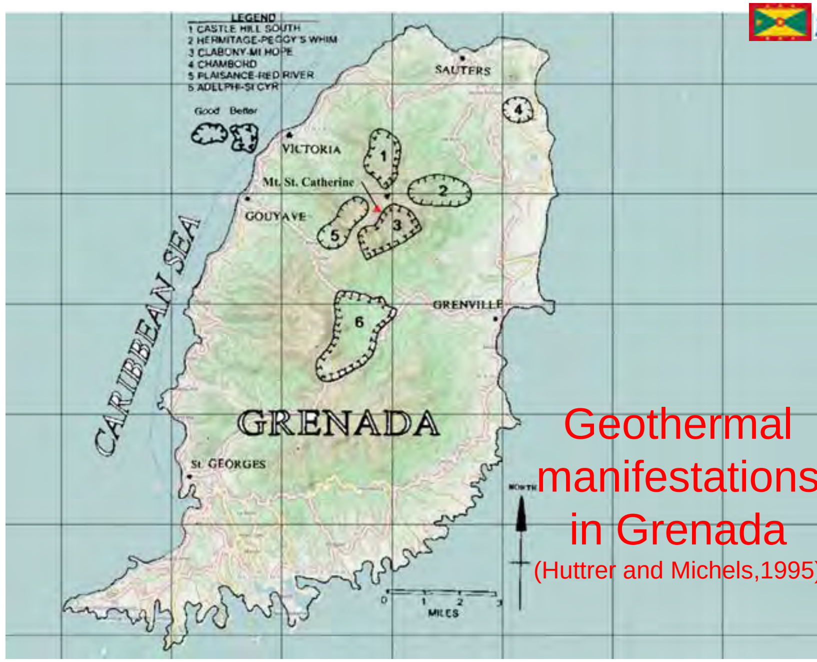


Figure 7: The most important geothermal Turbine manufacturer.

Geothermal potential of Grenada
and
Assistance from Japan



Present Situation in Grenada
- Our Understandings -

1. Geothermal Support Partnership Framework Agreement between the government of Grenada and New Zealand was agreed in 2014.
2. Geological, geochemical and geophysical survey is being conducted by an eminent New Zealand Consultant.
3. GRENLEC (a private owns 50% stocks) is only operator of electric sector.
4. Implementation framework is yet to be decided (i.e. implementation organization, financial arrangement and etc)

Present development stage

Almost completed — **Immediate requirement**

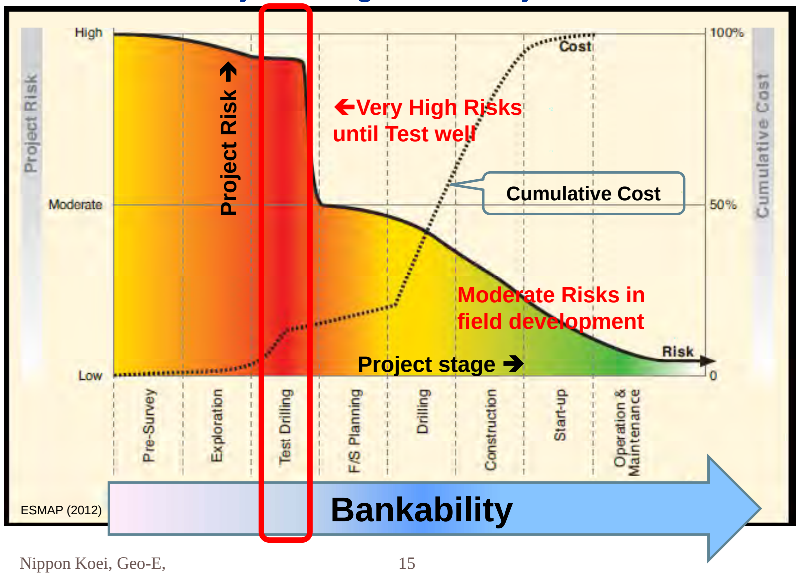
1. Pre-survey → **2. Surface Exploration** → **3. Test Well** → **4. Feasibility study**

To be conducted

5. Well construction → **6. Plant Construction** → **7. Commissioning** → **8. O & M**

This needs:
- **At least six years or more for completion.**
- **Persistent effort and consistent technical and financial support**

Project Stage and Project Risk



Possible cooperation from Japan
- *Consistent and Seamless Assistance* -

Scientific research and development
- To provide advanced scientific research for exploration and experienced skilful services for development,

Human resources development
- To contribute to human resource development with various programs,

Development policy and plan
- To propose practical development policy and to promote optimal development plan from technical and economical point of view,

ODA loan – CORE Scheme (IDB, CDB involvement)
- To finance the geothermal development with concessional loans

JICA Team's Queries and Views

JICA Team's Query and Views

I. Coordination with NZ assistance

1. To avoid duplications with NZ study, the government is kindly requested to provide the JICA Team with the reports and data of the NZ study, as soon as possible.
2. Please let us know what assistance NZ will provide after this surface survey.
3. Please let us know what assistance the government expects from NZ and Japan for geothermal development, a matter of demarcation.
4. We also would like to be informed how it is coordinated between NZ and Japan.

JICA Team's Query and Views

I. Development policy and priority

1. We understand the geothermal development has long been an issue for development. How is the priority ranking of the geothermal development in the National Development plan.

JICA Team's Query and Views

I. Legal matters

1. Regarding Electricity Supply Act (Draft) and Geothermal Development Act (Draft), we are aware that there are controversial points among parties concerned.
2. What are impacts on geothermal development from the two acts?
   - What are the processes for obtaining the test drilling license by whom ?
   - What would the government think the roles of GRENLEC in the geothermal development?

JICA Team's Query and Views

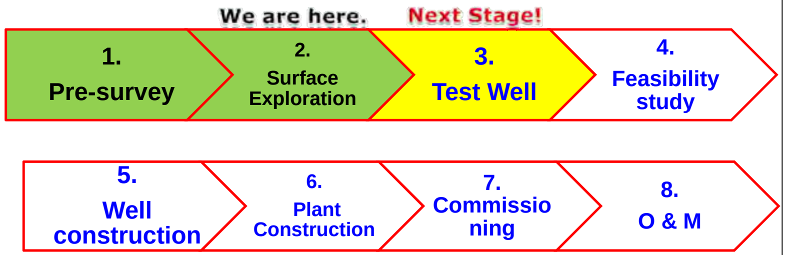
I. **Financial and Business Matter**

1. The public financing for geothermal development will significantly reduce the cost of capital. How would the government financially contribute to the geothermal development, for in particular test drilling? (e.g. debt guarantee, equity participation, other capital from government general budget, etc.)

JICA Team's Query and Views

I. **Environmental Social Impact Assessment (ESIA)**

1. Next stage is drilling test wells (approx.1,000-2,500m). What kind of ESIA is expected to be required ?



DATA COLLECTION SURVEY FOR
GEOTHERMAL DEVELOPMENT IN GRENADA

Overview of JICA's Contribution To Grenada Geothermal Development

June 2016
By Shinya TAKAHASHI

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Outline of JICA's Work

- Background
- Objectives
- Our Professionals

BACKGROUND (1/2): International Partnership

1. IDB and JICA entered in the agreement in 2013, on "**Cofinancing for Renewable Energy** and Energy Efficiency (CORE scheme)",
2. IDB, JICA and CDB entered in the Memorandum in 2014, aiming at building a new partnership to promote **renewable energy** and energy efficiency **in Eastern Caribbean Region.**

BACKGROUND (2/2): Project Identification by JICA

1. JICA conducted a preliminary survey in 12 CARICOM countries in 2014, to identify potential countries for renewable energy and energy conservation projects;
2. **Grenada** has been identified as one of the potential countries for geothermal development.

Objectives

1. To collect and review the existing data and information,
2. To conduct additional field surface surveys,
3. Thereby, to identify geothermal development project/s which JICA could extend its assistance,

➔ Through above activities, to promote a geothermal development project in Grenada.

JICA Team Nine (9) Professionals

Name	Responsible for	Firm
TAKAHASHI Shinya	Team Leader/ Geothermal Energy Development/ Reservoir Assessment	NK
AKATSUKA Takashi	Vice Team Leader/ Geology/ Drilling Planning	Geo-E
FUKUDA Daisuke	Geochemistry	Geo-E
KAWASAKI Kiyoshi/ TAKEDA Masahiro	Geophysical Survey	SRED
TERAMOTO Masako	Environmental Social Consideration	NK
KIKUKAWA Takeshi	Electricity Policy/ Investment Policy	(NK)
MOMOSE Yasushi/ YOSHIDA Satoshi	Civil Engineering Planning	NK

NK: Nippon Koei Co., Ltd.
Geo-E: JMC Goethermal Engineering Co., Ltd.
SRED: Sumiko Resource Exploration and Development Co., Ltd.,

Overview of JICA's Work

1. 3G surveys → 2. Integrated Reservoir Analysis → 3. Well targeting → 4. Test Well drilling design → 5. Scoping for ESIA → 6. Pre-F/S

In Collaboration with Japan and New Zealand

Works by NZ and Japan

1. 3G surveys → 2. Integrated Reservoir Analysis → 3. Well targeting → 4. Test drilling design → 5. Scoping for ESIA → 6. Pre-F/S

	Item	Sub-item	NZ	JAPAN	Delivery
Surface Surveys & Interpretation	1.	The 3-G surveys			
	1.1	Geology	☒	☒	
	1.2	Geochemistry	☒	☒	
	1.3	MT-survey	☒	-	
	1.4	Additional MT survey	☒		
	1.5	Gravity survey	-	☒	December
	1.6	MT 3-D analysis	☒	-	March
	1.7	Additional MT 3-D analysis	☒	-	March
	2.	Integrated Reservoir Analysis			
	2.1	Reservoir conceptual model	☒	-	March
	2.2	Reservoir assessment (MWe)	☒		March
Planning	3.	Well targeting			
		Proposal of well target	☒	☒	March

1. 3G surveys → 2. Integrated Reservoir Analysis → 3. Well targeting → 4. Test drilling design → 5. Scoping for ESIA → 6. Pre-F/S

T-Well Planning / ESIA / Pre-FS

Item		Sub-item	NZ	JAPAN	Delivery
1.		Planning of test drilling works			
	4.1	Drilling program(preliminary)		☒	June
	4.2	Assessment of port of unloading, land transportation		☒	June
	4.3	Civil work plan (including site access road)		☒	April
	4.4	Water supply plan		☒	June
	4.5	Other planning		☒	June
	4.5	Cost estimation(preliminary)		☒	June
2.		ESIA for drilling works			
	5.1	Baseline survey (secondary information survey)		☒	March
	5.2	Scoping		☒	March
	5.3	ESIA		◆	Next phase
3.		Pre-Basic design and Feasibility Study			
	6.1	Power plant		☒	June
	6.2	FCRS		☒	June
	6.3	Project cost		☒	June
	6.4	Project viability assessment		☒	June

☒:Completed, ◆: proposed to be conducted by additional funding

JICA survey schedule

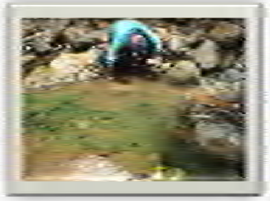
Data Review EIA survey | Gravity Survey & Analysis | Drilling site selection | Cost estimation & Pre F/S

No.	Position	Name	4	5	6	7	8	9	10	11	12	201 1	2	3	4	5	6	7
1	Team Leader/Geothermal Development Plan/Reservoir	TAKAHASHI		■		■		■									■	
2	Sub-Team Leader/ Geology/Drilling Engineer	AKATSUKA		■				■							■		■	
3	Geochemistry	FUKUDA		■														
4	Geophysics	KAWASAKI/ TAKEDA		■				■										
5	Environmental and Social Considerations Evaluation	TERAMOTO		■				■				■		■	■		■	
6	Energy Policy Analysis/Project Finance	KIKUKAWA		■		■						■		■			■	
7	Civil Engineering Planning	MOMOSE/ YOSHIDA		■				■							■			
	Report		△ IC/R							△ PR							△ DF/R	△ F/R

*Intermittent: Detailed survey plan will be made after the discussion.
IC/R: Inception Report, P/R: Progress Report, DF/R: Draft Final Report, F/R: Final Report

Today's Presentation by JICA team

1. **Drilling Plan** presented by **Akatsuka**
2. **Environmental and Social Consideration**, presented by **Dr.Teramoto**
3. **Financial Analysis and Feasibility Study**, presented by **Dr. Kikukawa**



Matsukawa Geothermal Power Generation, Japan


Continuous 50 years operation since 1966

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT

Delivering the drilling plan

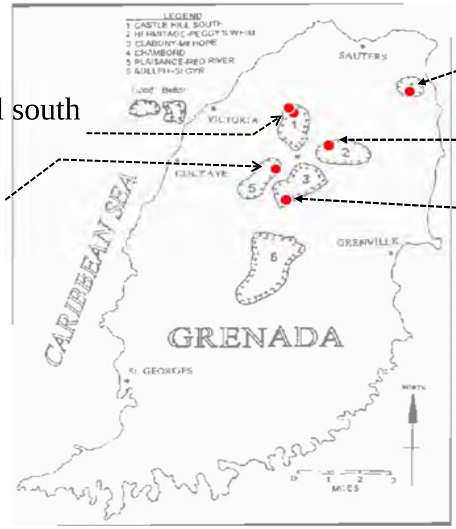
June 23, 2016

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Contents

Geothermal manifestations in Grenada



Source:Huttrer & Michels (1995)

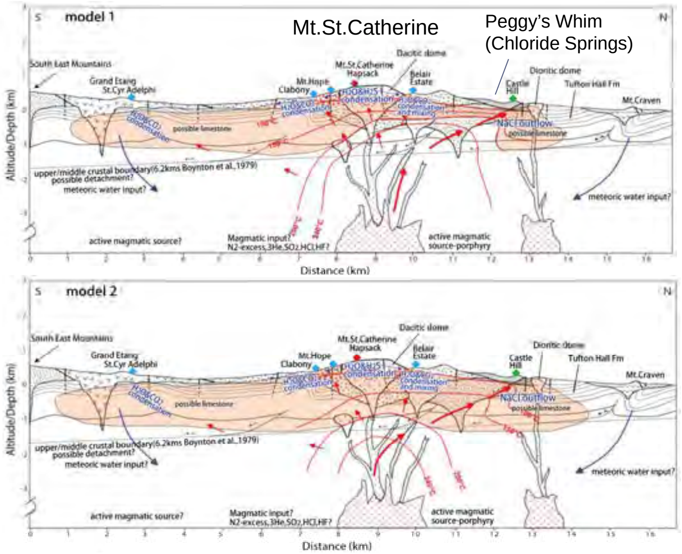
Geothermal manifestations in Grenada

Mudpaste for beauty?

Chambord
Temp32.7 degrees C (field)
Salty, Travertine (Calcite)

Peggy's Whim
Temp 38.7 degrees C (field)
Geothermal alteration

2 models of geothermal in Grenada



Cap rock
thin or thick ?

Upper & Outflow zone
Good permeability
200-220 degrees C
Or
Outflow zone
less permeability
100-160 ℃

Deep reservoir
Shallow and wide
Or
Deep and narrow

Source:Jacobs(2016)

3G(Geology, Geochemistry and Geophysics) surface surveys reveal the potential and possible location of geothermal resource in GRENADA. But,

Main Risks before drilling full-size well are in below

1) Reservoir Temperature

Boiling thermal features are common in many geothermal fields. But,….

2) Permeability

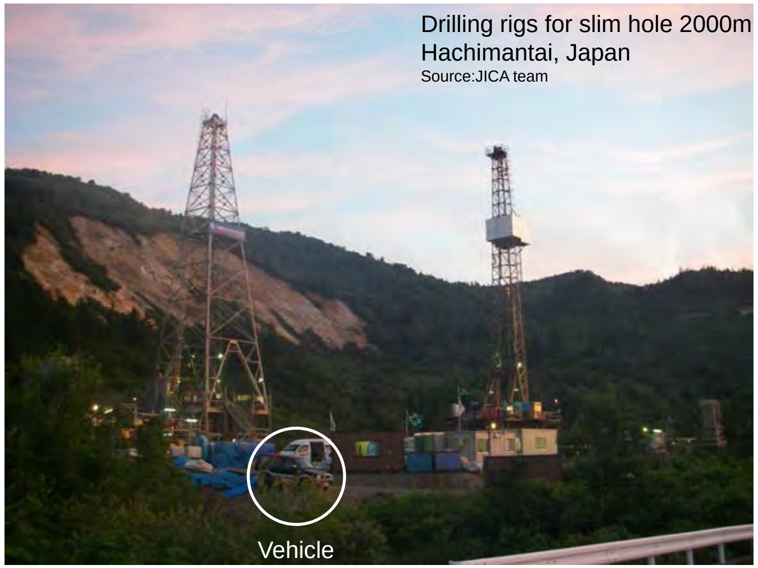
Many volcanic geothermal field are hosted in volcanic deposits.
Geothermal Reservoir under Mt. St. Catherine would correspond to sedimentary deposits.

3) Size of the reservoir

Hydrothermal and native smectite may cause over estimating the size of reservoir.

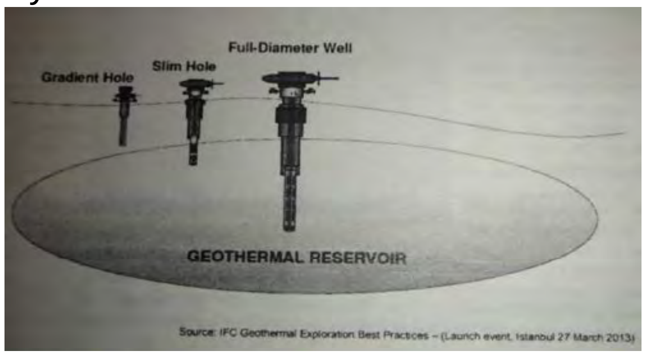
>>SLIM HOLE is best on next stage.

1. SLIM HOLE



CONCEPT OF SLIM HOLE

- Smaller diameter than full-size wells
- Normally drilled into the reservoir



- Drilled using BOP(Blow Out Preventer) equipment with light-medium range oilfield Rigs.

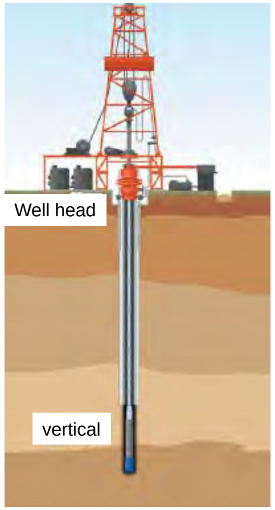
Purpose OF SLIM HOLE

- Collection of underground date
  - Reservoir temperature
  - Pressure
  - Geology
  - Permeability (fractured or not)
  - Hydrothermal alteration

- Improvement of geothermal model
- Evaluation of geothermal potential

- Revealing the promising area for APPRAISAL WELLs

>>Contribution to be more successful.



Source: JOGMEC

Advantages OF SLIM HOLE

- Cost
- Time to start
- Small space (approximately 2000m^2)

Drilling rig for slim hole 2000m
Hachimantai, Japan
Source:JICA team

Procedure of SLIM HOLE drilling

1. Planning

2. Site Preparation (< a few month)
3. Rig up & installation of water supply line(<1month)
4. Drilling (several month)
5. Rig down(<1month)

6. Vegetational reclamation
7. Data analysis

Procedure of SLIM HOLE drilling

1. Planning

- Drilling depth
- Target
- Casing program
- Drilling equipment (rig, pump etc)

- Time schedule
- Licensing Procedure
  - Negotiation with related government agencies, landowners
  - Permission
- Cost

Procedure of SLIM HOLE drilling

2. Site Preparation (< a few month)

- Tree trimming and change in geometry (making flat space) >>for drilling pad, temporary equipment space..
- Setting the temporary road

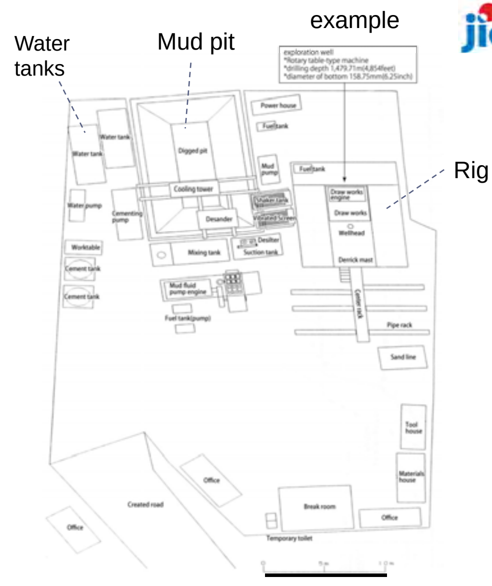
Tree trimming

Vegetation on digged slop

Source: JOGMEC

Drilling pad

- Approximately 2000m^2 =40m*50m is needed for drilling equipment.
- water supply pit
- space for temporary construction material



Procedure of SLIM HOLE drilling

3. Rig up & installation of water supply line(<1month)

Conveyance of drilling equipments.
>>Assembling rig, water supply line, mudfluid circulation sustem etc…(Rig up)

Source:JICA team

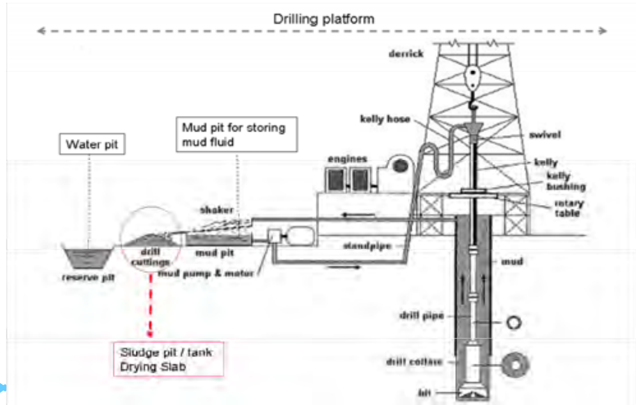
Rig of SLIM HOLE

1.Rotary table-type Truck-mounted rig
Source: http://www.esmap.org/sites/esmap.org/files/Bailey_Exploration(Day1)_0.pdf

2. Spindle-type boring machine
Source: http://toa-tone.jp/manufacture/m03.html#m03

Water is important role for Drilling

- Drilling fluid (water + clay + polymer)
  Cooling bit, Removing cuttings, covering wall.
- Injection water into well to prevent blowout.



Amount used of Water for Drilling

- Drilling without loss circulation
  A small amount of water (approximately a few ton per minute)
  >>Mainly resupply amount of evaporated water
- Drilling with loss circulation, cementing
  Large amount of water (approximately 2-3 ton per minute)
  >>In case of water flowing out well by way of several fractures.

Water Supply Pit

- water supply pit (about 12m × 12m × 1m ≈ 150m^3 is needed, equivalent 5 times volume of the slim hole.

Source:JICA team

Source:JICA team

Procedure of SLIM HOLE drilling

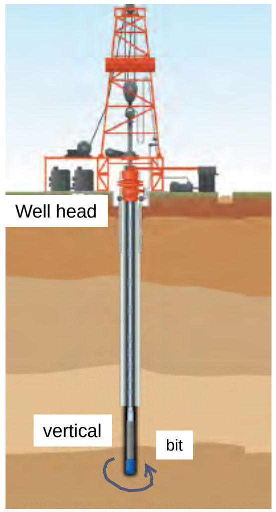
4. Drilling (< several month)

Spindle-type machine

Core bit

Collecting core sample

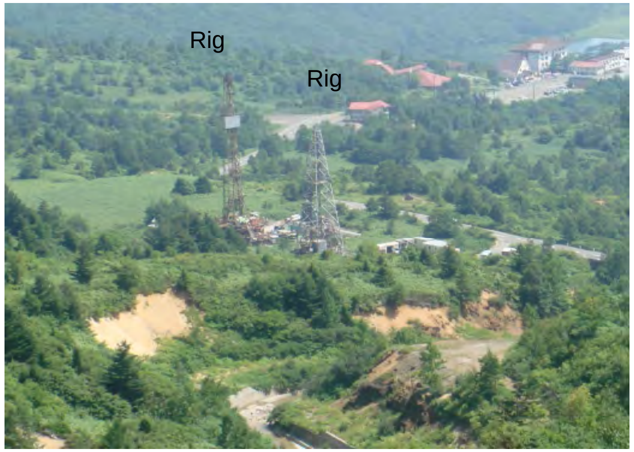
analysis core sample



Source: JOGMEC

Procedure of SLIM HOLE drilling

Drillings on going…..



Source: JOGMEC

Procedure of SLIM HOLE drilling

5. Rig down (< 1 month)

6. Vegetational reclamation
7. Data analysis

- Geology, physical properties (temperature, pressure etc.) in drilled well
- Improvement of geothermal model
- Planning of appraisal well (target, drilling procedure etc.)

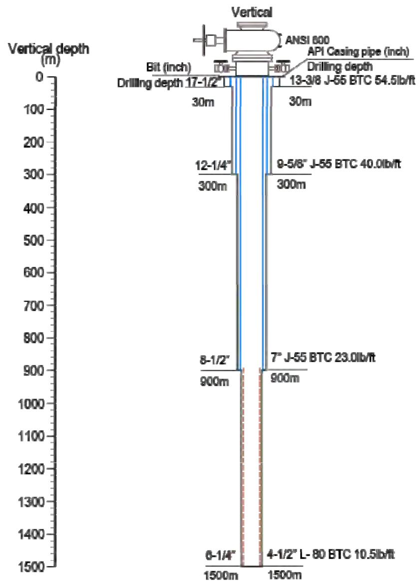
GO on to NEXT STAGE

Source: JOGMEC

2. Recommendation

- Rig
- Drilling depth and Casing program
- Intake water
- Location and access

Well program drilled by rotary-table

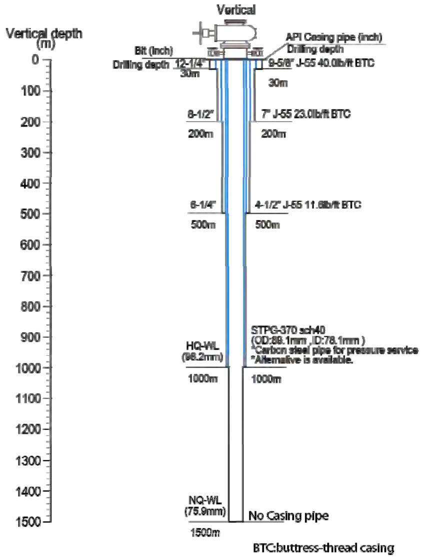


Drilling Rig:Rotary table-type Truck-mounted rig

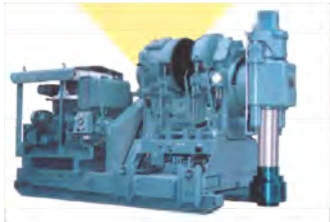
Casing pipe: API (American Petroleum Institute) Standard
*Insert casing pipe into bottom of well.

Logging Items
Pressure-Temperature logging
Wellsite Geology
description of lithology (cuttings, core sample)

Well program (drilled by Spindle-type)



Drilling Rig:Spindle-type boring machine

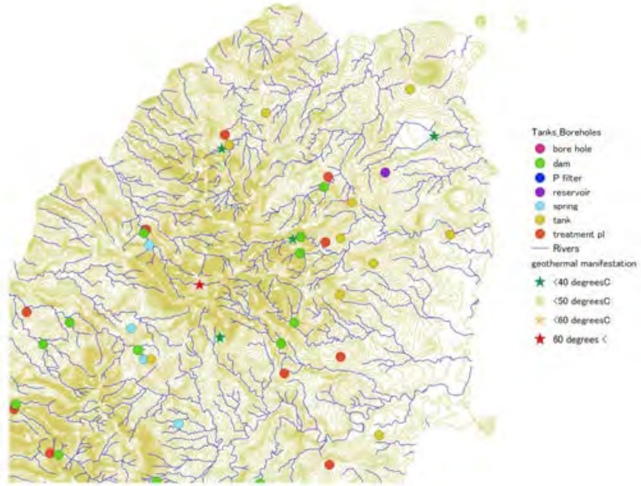


Casing pipe: API (American Petroleum Institute) Standard
*Insert casing pipe into bottom of well.

Logging Items
Pressure-Temperature logging
Wellsite Geology
description of lithology (cuttings, core sample)

Water intake

Intake are recommended to locate the down the stream of NAWASA's facility.
Negotiation and agreement from NAWASA are needed to use river water for drilling.

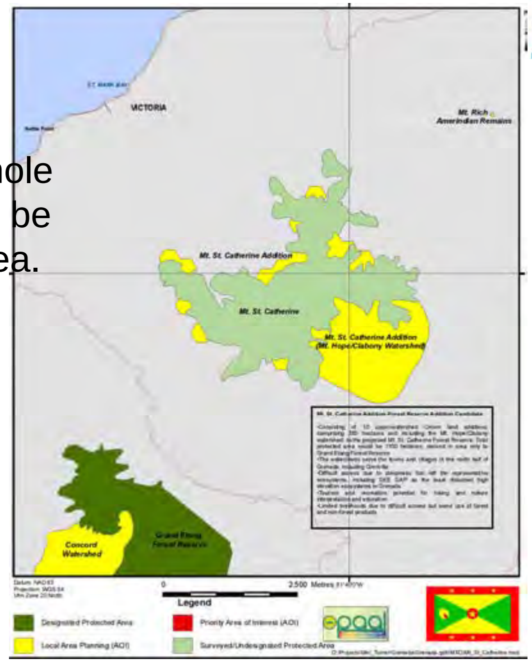


Location of drilling pad

Drilling pad for slim hole are recommended to be accessible.

Location of drilling pad

Drilling pad for slim hole are recommended to be out of the reserve area.



Conclusion

- SLIM HOLE is best choice for the geothermal development in Grenada.
- It is possible to obtain the data of pressure-temperature distribution, geology and fracture information, and reservoir pressure to evaluate geothermal reservoir.
- SLIM HOLE is designed as vertical, 1,500 meters in depth.
- Agreement of Landowners are needed to proceed slim hole drilling.
- Negotiation and agreement from NAWASA are needed to use river water for drilling.

Thank you

DATA COLLECTION SURVEY FOR
GEOTHERMAL DEVELOPMENT IN GRENADA

Environmental and Social Considerations for Geothermal Project

Partners' Forum

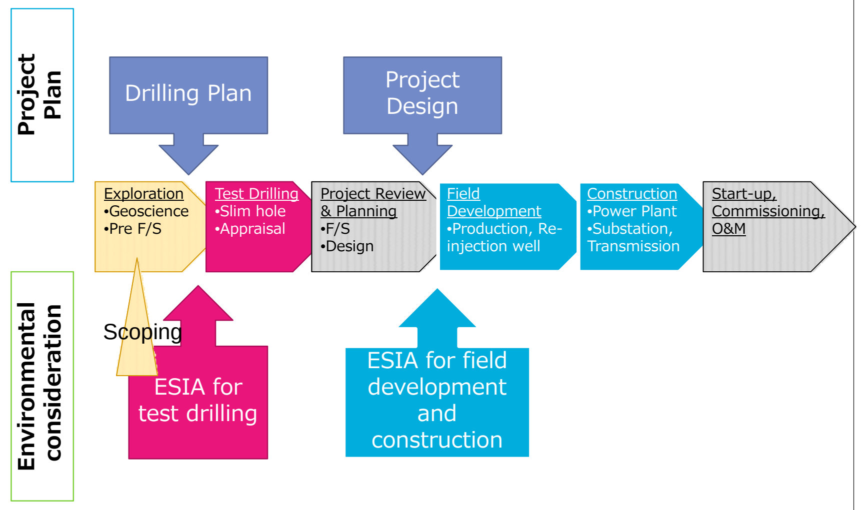
24th June 2016

Masako TERAMOTO

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Geothermal Development Stage and ESIA



NIPPON KOEI Geo-E

Legal Framework of Environment

for geothermal development
in Grenada

EIA Legislation

◆Two legislations include provisions for environmental impact assessment (EIA) in Grenada.
◆Physical Planning Development Authority (PDA) and the minister responsible for environmental planning.

No.	Legislation	Description
1	Physical Planning and Development Control Act No. 25 of 2002 Physical Planning and Development Control Bill, 2015 (Draft)	To make provision for the control of physical development, require the preparation of physical plans for Grenada, protect the natural and cultural heritage, and for related matters.
2	Waste Management Act No. 16 of 2001	To provide for the management of waste in conformity with best environmental practices and related matters

NIPPON KOEI Geo-E

Development Activity Requiring EIA

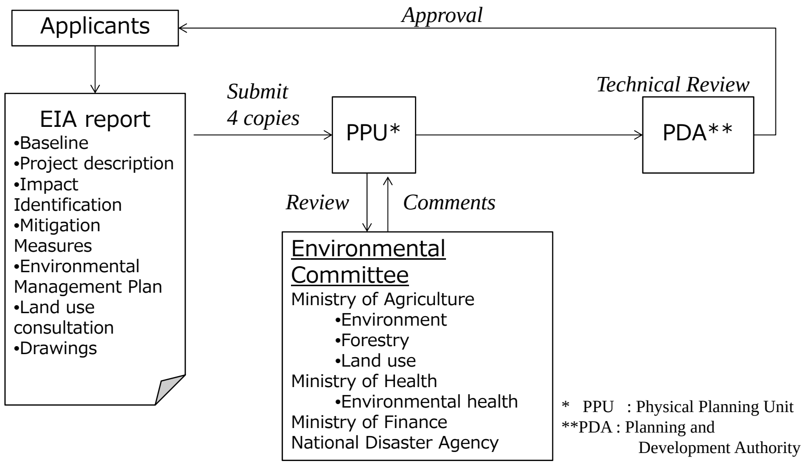
- 18 development activities listed below are subject to EIA.
- Geothermal development activities are classified in No.10, No.15 and No.18.

No.	Types of Development
1	Hotels of more than 50 rooms
2	Subdivisions of more than ten lots
3	Residential development of more than 25 units
4	Any industrial plant which in the opinion of the authority is likely to cause significant adverse environmental impact
5	Quarrying and other mining activities
6	Marinas
7	Land reclamation, dredging, and filling of ponds
8	Airports, ports, and harbors
9	Dams and reservoirs
10	Hydroelectric projects and power plants

Development Activity Requiring EIA

No.	Types of Development
11	Desalination plants
12	Water purification plants
13	Sanitary landfill operations, solid waste disposal sites, toxic waste disposal sites, and other similar sites
14	Gas pipeline installations
15	Any development generating or potentially generating emissions, aqueous effluent, solid waste, noise, vibration, or radioactive discharges
16	Any development involving the storage and use of hazardous materials
17	Any coastal zone development
18	Any development in wetlands, marine parks conservation areas, environmental protection areas, or other sensitive environmental areas.

EIA Process in Grenada



- After submission of the EIA report to the Physical Planning Unit, it normally takes about six weeks for the report to be approved.

Relevant Environmental Legislations and Regulations

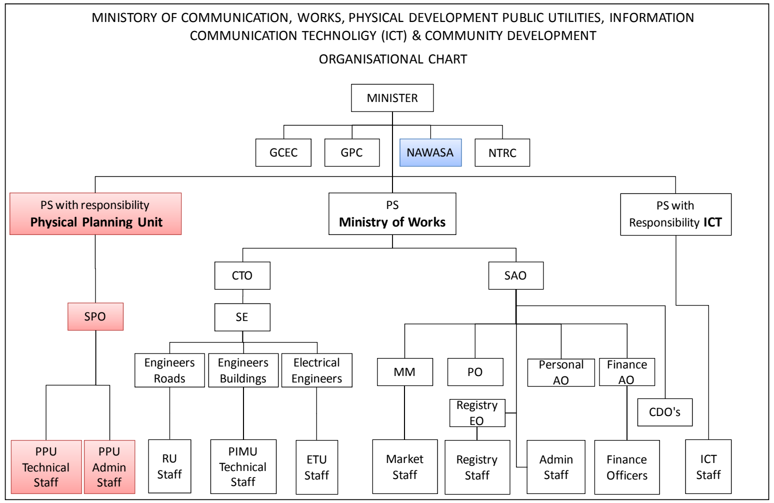
No.	Legislation	Description
1	The Beach Protection Amendment Act of 2009	To prohibit sand mining in Grenada.
2	Litter Abatement Act of 1973	It has been supplemented by the passage of the Waste Management Act of 2001 addressing pollution control and abatement of litter.
3	Solid Waste Management Act No. 11 of 1995	It has established the Solid Waste Management Authority charged with the duty of developing solid waste management facilities and improving the coverage and effectiveness of solid waste storage, collection, and disposal facilities of Grenada.
4	National Parks and Protected Areas Act of 1991	To designate and maintain national parks and protected areas.
5	Environmental Levy Act No. 5 of 1997	To impose and collect environmental levy on certain goods and services.
6	Fisheries Act of 1986	To provide for the protection of the marine resources in Grenada; amended in 1999.
7	Forest, Soil, and Water Conservation Act, 1949	To make provision for the conservation of the forest, soil, water, and other natural resources of Grenada; amended in 1984.

Institutional Framework

◆Currently following institutions are directly involved in environmental management activities in Grenada.

No.	Institutions
1	Physical Planning Unit, Ministry of Communication, Works and Physical Planning
2	Forestry Department, Ministry of Agriculture Forestry and Fisheries, Public Utilities, Marketing Board and Energy
3	Department of Environment, Ministry of Agriculture Forestry and Fisheries, Public Utilities, Marketing Board and Energy
4	Land Use Department, Ministry of Agriculture, Forestry, Fisheries, and Marketing Board
5	Environmental Health Department, Ministry of Health and the Environment
6	Solid Waste Management Authority
7	National Water and Sewage Authority (NAWASA)
8	Port Authority
9	Airport Authority

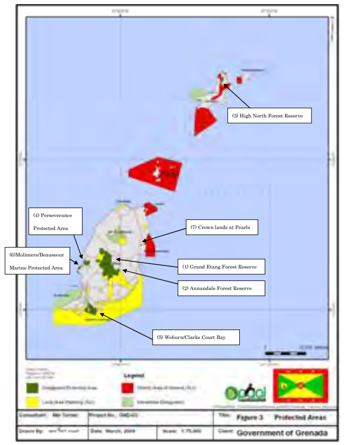
Organizational Structure



Environmental and Social Conditions

of geothermal development project in Grenada

Natural and Cultural Heritage



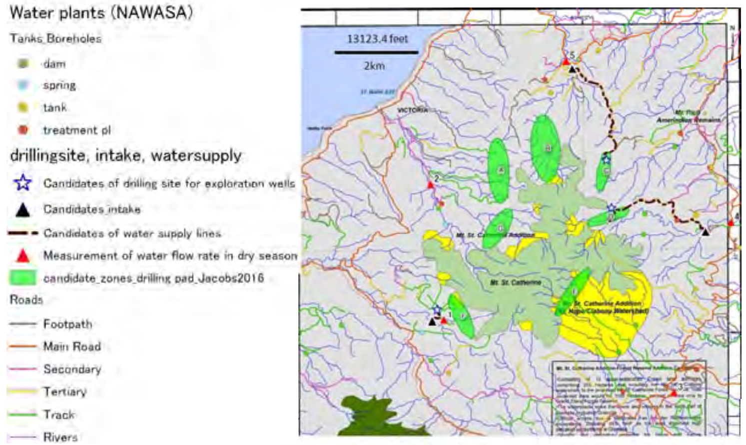
1. Grand Etang Forest Reserve
2. Annandale Forest Reserve
3. High North Forest Reserve
4. Perseverance Protected Area
5. Woburn/Clarks Court Bay Marine Protected Area
6. Moliniere/Beausejour Marine Protected Area
7. Unspecified crown lands at Pearls are designated as a protected area

Types of Protected Area

Category	Feature	Area (Selected)	Designation
Designated Protected Area	Already designated by the government (7 areas)	Grand Etang	Forest Reserve
Local Area Planning	Areas that should be reviewed in the context of best land use and the local area planning process. (14 areas)	Mt. St. Catherine Addition	Mt. St. Catherine Forest Reserve Addition
Priority Area of Interest	Existing land use pressures from residential, tourism, and industrial development have the potential to threaten future protected area. (8 areas)	South Carriacou Islands	Marine Protected Area
Immediate Designation	Areas which should be designated immediately due to the importance to Grenada's endangered species and habitats. (16 areas)	Mount Hartman	National Park
		Mt. St. Catherine	Forest Reserve

- In Grenada, there are several endemic species of flora and fauna.
- Need to be assess environmental impact from the project.

Location of Protected Area and Drilling Candidate Areas



- In Grenada, the center part of Mount St. Catherine and parts of coast area are designated as protected areas. All the drilling candidate zones is outside these protected zones.

Hydrological Environment

- 71 watershed areas (left).
- There are 11 boreholes, 17 water storage tanks, and 24 water treatment tanks (right)

- Need to avoid negative impact on water resource by drilling activities regarding both quantity and quality.

Social Environment

- Land Use:
  - Agriculture (light green)
  - Abandoned cultivation(yellow)
  - Forest (green)
- Local Economy:
  - Most of residents around Mr.St.Catherine make a living by agriculture.
    - Nutmeg, cocoa, banana, sugarcane and other fruits.

- There might be some land acquisition and replacement needed for geothermal project.

Results of Preliminary Scoping

for geothermal development
in Grenada

Results of Preliminary Scoping

◆In order to identify items for ESIA for the geothermal project in Grenada, preliminary scoping was conducted.
◆Check items listed below are selected based on the JICA Guidelines for Environmental and Social Considerations (April 2010)

RATING

- A+/-: Significant positive/negative impact is expected.
- B+/-: Positive/negative impact is expected to some extent.
- C+/-: Extent of positive/negative impact is unknown (further examination is needed, and its impact could be clarified as the study progresses)
- D: No impact is expected.

Results of Preliminary Scoping

Category: "Pollution(1/2)"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
1	Air Quality	B-	B-	B-	Pre・Con : During production test, generation of gas containing hydrogen sulfide (H2S) is expected. In addition, emission gases are discharged due to operation of heavy machines during well drilling and facility construction. Ope : H2S is expected to be released along with steam.
2	Water Quality	B-	B-	B-	Pre・Con : Mud water is expected to be generated due to well drilling. Ope : Wastewater is expected to be discharged from the facilities.
3	Wastes	B-	B-	B-	Pre・Con : Drilling sludge, construction waste soil, and scrap wood are expected to be generated by well drilling activities. Ope : Wastes (sludge, waste oil) are expected to be generated in the facilities.
4	Soil Pollution	D	D	D	No activities which may cause soil pollution are planned.

Results of Preliminary Scoping

Category: "Pollution(2/2)"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
5	Noise/ Vibration	B-	B-	B-	Pre・Con : Blowout of geothermal fluid by well drilling and noise from operation of heavy machines are expected. Ope : Noise from operation of the facilities (power generator, steam turbine, cooling tower, etc.) is expected.
6	Ground Subsidence	D	D	C	Pre・Con: Collection of geothermal fluid during well drilling and facilities construction is limited. Ope : Although ground subsidence is expected due to collection of geothermal fluid, detailed examination is required.
7	Offensive Odor	C	C	C	If gas contains hydrogen sulfide (H2S), odor is expected.
8	Sediment Quality	D	D	D	No activities which may cause sediment quality pollution are planned.

Results of Preliminary Scoping

Category: "Natural Environment"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
9	Protection Area	A-	A-	A-	The project site is located close to Mt. St. Catherine Forest Reserve.
10	Ecosystem /Flora and Fauna	A-	A-	A-	Some negative impacts on regional ecosystem and flora and fauna are expected due to disturbance of the land, operation, and existence of the facilities.
11	Hydrology	B-	B-	D	Pre・Con : Surface water or groundwater is planned to be used for drilling. Ope : The amount of surface water or groundwater planned to be used is limited.
12	Topograph y/ Geology	D	B-	D	Pre : Impacts are negligible as large-scale well drilling is not planned. Con : The land is expected to be disturbed due to construction of facilities (generator building, steam and hot fluid transport pipe, cooling tower, etc.). Ope : No activities which may cause impacts on topography/geology are planned.

Results of Preliminary Scoping

Category: "Social Environment(1/4)"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
13	Involuntary Resettlement	C	C	C	Even though there are few residents around the project site, involuntary resettlement survey is required after the drilling plan.
14	Poor People	D	B+	B+	Pre : Creation of employment opportunities from test drilling is limited. Con・Ope : Some positive impacts on regional economy are expected such as creation of employment opportunities through construction and operation of the facilities.
15	Ethnic Minority/ Indigenous People	D	D	D	There are herders and nomads available in the area, but there are no ethnic minorities or indigenous people who need special consideration.
16	Local Economy and Livelihood	D	B+	B+	Pre : Test drilling only creates limited employment opportunities. Con・Ope : Some positive impacts on regional economy such as creation of employment opportunities are expected by the construction and operation of the facilities.

Results of Preliminary Scoping

Category: "Social Environment(2/4)"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
17	Land Use and Utilization of Local Resources	D	D	B+	Pre・Con : No impacts on land use and utilization of local resources are expected. Ope : Geothermal fluid could be used for other purposes in addition to geothermal generation.
18	Water Use	A-	A-	D	Pre・Con : Surface water or groundwater is planned to be used for drilling. Some impacts on water resource are expected.. Ope : The amount of surface water or groundwater planned to be used is limited.
19	Social Infrastructures and Services	D	D	D	There are no sensitive social infrastructures (dwelling, school, medical facilities, etc.) located in and around the project site.
20	Social Institutions and Local Decision-making Institutions	D	D	D	No impacts on social institutions and local decision-making institutions are expected.

Results of Preliminary Scoping

Category: "Social Environment(3/4)"

No.	Items	Rating			Rating Basis
		Pre	Con	O&M	
21	Misdistribution of Benefits and Damages	D	D	D	No unequal distribution of benefit and damage is expected in and around the project site.
22	Local Conflicts of Interest	D	D	D	No local conflict of interest is expected in and around the project site.
23	Cultural and Historical Heritages	C	C	C	Although no cultural and historical heritages were considered at the project site, a detailed investigation is required.
24	Landscape	D	D	A+/-	Pre・Con : Since no large-scale construction work is planned, impacts on landscape are temporal and limited. Ope : Some impact on landscape is expected due to the existence of plant facilities (power generator, steam turbine, cooling tower, etc.).

Results of Preliminary Scoping

Category: "Social Environment(4/4)"

No.	Items	Rating Pre	Rating Con	Rating O&M	Rating Basis
25	Gender	D	D	D	No impact is expected.
26	Children's Rights	D	D	D	No impact is expected.
27	Infectious Diseases (such as HIV/AIDS)	B-	B-	D	Pre・Con： Although no large-scale construction work is planned, there is a possibility for infectious diseases to spread due to the influx of workers. Ope：Since the number of workers at the project facilities is limited, impact on infectious disease is considered to be small.
28	Occupational Environment (including Occupational Safety)	C-	C-	C-	Although the project site is located at not special area, some sort of considerations on occupational safety are required.

Results of Preliminary Scoping

Category: "Others"

No.	Items	Rating Pre	Rating Con	Rating O&M	Rating Basis
29	Accidents	B-	B-	B-	Special considerations on accidents are required during test drilling, facility construction, and operation.
30	Climate Change	D	D	A+	Pre・Con：Since no large-scale construction work is planned, impact on climate change is temporal and limited. Ope：This project could contribute to reduce greenhouse gas emission.

Compliance with International Requirement

- ToR to be included in an ESIA are specified in the physical planning and development control act No.25 of 2002.
- They are largely in line with the requirement specified in JICA guidelines for environmental and social considerations (2010), however, Grenadian regulations do not require intensive attention on social impact assessment.
- In order to comply with JICA's guidelines as well as other international requirement such as IFC, it is proposed to include following studies.
  1. Evaluation of alternatives including zero option
  2. Social impact study including land acquisition and resettlement
  3. Public consultation

Proposed ToR for ESIA for Next Phase

1. Baseline survey
2. Stakeholder Engagement Plan (SEP)
3. Environmental and Social Studies
   - Biodiversity
   - Water
   - Noise
   - Air quality
   - Socoi-Enocomics and Cultural Heritage
   - Involuntary Resettlement (physical and economic displacement)
4. Impact Assessment
5. Environmental and Social Management Plan (ESMP)
6. Environmental and Social Management System (ESMS)
7. Consultation and Disclosure

Thank you very much
for your attention

DATA COLLECTION SURVEY FOR GEOTHERMAL DEVELOPMENT

Financial Analysis for Geothermal Project

June 2016

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CONSULTANTS;
NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT CO., LTD

Project Design Summary

Project Overview (1/3)

1. Project Overview	
1.1 Project Description	
The project shall include the following activities. - Geothermal resources assessment, - Geothermal well drilling and testing - Construction of Geothermal Power Plant (15MW or 10-15 MW to be examined.) - Construction of Transmission Line (out of scope of development of generation) - Operation and Maintenance of the Power Plant	
1.2 Goal and Objectives	
- To reduce and stabilize electricity prices - To contribute to the mitigation of the global warming	The ceiling price of the energy cost can be considered to be 0.15 USD/kWh given the current cost of services of GRENLEC.
1.3 Decision Management	
- Currently the assessment of the pre-feasibility of the resources is being carried out. - The procurement of fund for the exploration drilling is considered in parallel.	The development stage is generally subdivided into six steps. 1. Initiate, 2. Evaluate Resource , 3. Quantify Resource, 4. Confirm Resource, 5. Execute, 6. Operate
1.4. Project Ownership, Structure and Governance	
The formation for project development is being examined.	
1.5 Policy and Legislative Framework	
Law: - Public Utilities Regulatory Communication Bill 2015: being discussed at Parliament - Electricity Supply Bill 2015: being discussed at Parliament - Geothermal Development Bill: being drafted. Policy The Energy Division in the Ministry of Finance, Planning, Economy, Energy & Cooperatives (Ministry of Finance) is in charge of energy policy.	It would also be envisages that a PPP-related regulations would be established.

Project Overview (2/3)

2. Investment

2.1 General Conditions

Main procurement will be conducted through open book method in compliance with the international cooperating partners.

2.2 Cost Estimates

Construction costs for Model 3 are as follows.

(i) Government Portion

Category	Item	Costs (USD mil.)	%
Well Drilling	Civil Works	0	0.0
	Slimhole Drilling	0	0.0
	Appraisal Drilling	0	0.0
	Production Drilling	0	0.0
	Consultancy Services	0.75	100.0
Power Plant Development	Field Dev.	0	0.0
	Power Plant Dev.	0	0.0
	Transmission Line	0	0.0
	Consultancy Services	0	0.0
Total Project Costs		0.75	100.0

(ii) Private Portion

Category	Item	Costs (USD mil.)	%
Well Drilling	Civil Works	13.10	11.89
	Slimhole Drilling	0.00	0.0
	Appraisal Drilling	20.80	18.87
	Production Drilling	12.40	11.25
	Consultancy Services	4.08	3.70
Power Plant Development	Field Dev.	6.60	5.90
	Power Plant Dev.	35.22	31.96
	Transmission Line	18.00	16.34
	Consultancy Services	0.00 (included in the above)	0.00
Total Project Costs		110.20	100.0

Project Overview (3/3)

2.3 Project Profile

The followings are assumed for the base case

- Installed Capacity 5.5 MW x 3 Unit, total 16.5 MW
- In house use 10
- Availability factor 90
- Net output 15 MW
- Annual generation Net 118.2 GWh/year
- Construction period Vary by model
- Operating period 30 years

2.4 Project Schedule

Project Schedule for Model 3 is estimated as follows.

Item	Period (year)	Remarks
Permissions & Civil Works	1.0	By Government (Public)
Slimhole Drilling	1.0	
Tendering	2.0	
Civil Works & Preparation	1.0	By Private
Appraisal Drilling	1.0	
Production Drilling & Field Development	1.0	
Transmission Line	1.0	
Power Plant & Commissioning	1.0	
Total Period	9.0	

The assumption figures for the other models are as described in the other sections of the report.

Project Costs

The activities after the surface survey include;

i) slimhole drilling,
ii) appraisal well drilling,
iii) production well drilling,
iv) transmission facility construction, and
v) power plant construction including steam field development.

The estimation cost totaled to 123 million USD.

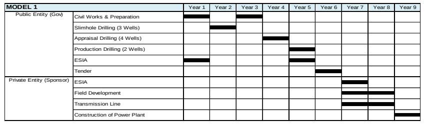
Cost Items	Cost (US$)
Civil Works & Preparation	17,700,000
Slimhole Drilling (3 Wells)	7,500,000
Appraisal Drilling (4 Wells)	20,800,000
Production Drilling (2 Wells, Production Test)	12,400,000
Field Development	6,000,000
Construction of Power Plant	35,200,000
Transmission Line (2 lines)	18,000,000
Consultancy Services (DD, SV)	5,800,000
Total	123,400,000

Project Scheme

Model #	Slimholes	Appraisal Drilling	Production Drilling	Field Dev & Power Plant
Model 1	Gov	Gov	Gov	Private
Model 2	Gov	Gov	Private	Private
Model 3	Gov	Private	Private	Private
Model 4	n/a	Private	Private	Private

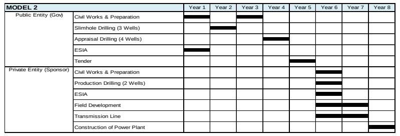
Project Schedule

Model 1



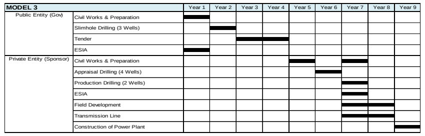
9 Years

Model 2



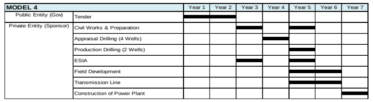
8 Years

Model 3



9 Years

Model 4



7 Years

Financial Analysis

Sample Development Phase

1. Phase I : Preparation (Indicative Duration: 2015 - 2016)
1) Surface Exploration
2) Conceptualization

2. Phase II : Exploration (2017 - 2019)
1) Slimhole Drilling
2) Confirmation of Resources
3) Concession Award

3. Phase III : Appraisal (2019 – 2020)
1) Appraisal Drilling
2) Feasibility Study/ Arrangement of Debt Financing

4. Phase IV : Production Drilling/ Construction (2021 – 2024)
1) Production Drilling/ Field Development
2) Construction of Power Plant
3) Substation & Transmission Line

5. Phase V : Operation and Maintenance (Commissioning in 2025 – 2026)
1) Operation and Maintenance of Power Plant
2) Management of Geothermal Reservoir

Project Scheme

Particular		Model 1	Model 2	Model 3
		Separation of Power Plant (PPP Model no.1)	Separation of Production Drilling (PPP Model no.2)	Separation of Appraisal Drilling (PPP Model no.3)
Development Activity & Entity	1. Exploration Slimhole Drilling	Government (Grant Fund)	Government (Grant Fund)	Government (Grant Fund)
	2. Appraisal Drilling	Government	Government	Private
	3. Production Drilling	Government	Private	Private
	4. Field Development & Construction of Power Plant	Private	Private	Private
	5. Operation	Private	Private	Private
Debt Financing	Government	Concessional Loan	Concessional Loan	Concessional Loan
	Private	Commercial Loan	Commercial Loan	Commercial Loan
Remarks		Sales agreement of steam OR Sales of production wells to power producer	Transfer cost of appraisal drilling to power producer	No costs will be transferred to private entity.

Source: JICA Survey Team (2016)

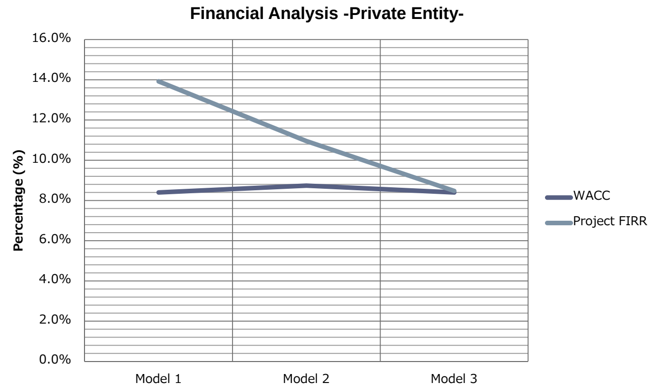
Assumptions for Analysis

Item	Condition
a. Energy Generation	118.2 GWh/year (Average utilization rate; 90%)
b. Initial Investment Costs	110.20 USD mil. (model 3, private entity)
c. Total Construction Period	Vary by model
d. Project Period	Operation; 25 years from commissioning
e. Ratio of capital procurement (equity & debt)	Vary by model
f. Repayment of Debt	Concessional loan: 25 years (grace period; 7 years) Commercial loan; 20 years (grace period; 3 years)
g. Capital Costs	Concessional loan: 3.0% Commercial loan; 5.5%
h. Annual O&M Expenses	2.0% of total construction cost
i. WACC	Vary by model
j. Depreciation	Service life: 30 years, Salvage value: 5%, Straight-line method
k. Tax &Duty	Corporate tax: 30%, VAT & Import Duty: exempted.
l. Physical Contingency	5% of total costs
m. Power Sales Price	Generation Company to GRENLEC; US 15.0 cents/kWh
n. Charges from Public to Private (Generation Company)	Vary by model

(1/2)

Entity	Item	Model 1	Model 2	Model 3
Public (Government)	Debt	US$ 41.5 mil.	US$ 27.1 mil.	US$ 0.6 mil.
	Equity	US$ 20.6 mil.	US$ 13.8 mil.	US$ 0.3 mil.
	WACC[1]	2.6□	2.6□	2.6□
	Project FIRR	3.5%	3.7%	4.3%
	Equity FIRR	-1.1%	-0.9%	1.7%
Private	Debt	US$ 50.3 mil.	US$ 66.3 mil.	US$ 92.6 mil.
	Equity	US$ 12.6 mil.	US$ 19.1 mil.	US$ 23.1 mil.
	WACC	8.4□	8.7□	8.4□
	Project FIRR	13.9%	11.0%	8.5%
	Equity FIRR	34.9%	31.8%	22.2%
Public-Private Consolidated	Project FIRR	8.2%	8.4%	8.4%

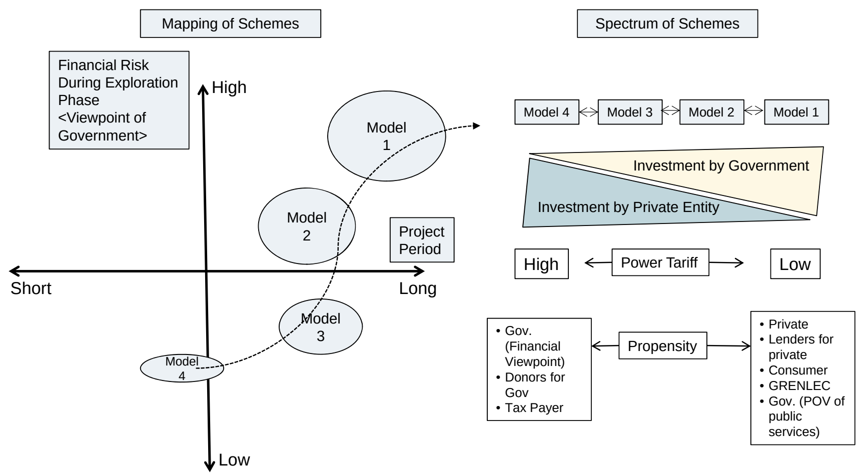
(2/2)



Implication for Power Tariff

#	Assumption	Indicator		Model 1	Model 2	Model 3
1.	Power Sales Tariff to Off-taker (15.0 US cents/kWh)	Equity FIRR	%	34.9%	31.8%	22.2%
2.	Equity Return (Target: 20%)	Power Sales Tariff	c/kWh	12.1	12.9	14.3

Scheme



Observations & Recommendations

1. Government Role and Financing
2. Investment Policy of Government
3. Capacity Development
4. Legislation and Regulation
5. Improvement of Project Survey
6. Market Sounding

Roles of Government

Government Policy
(1) Sector Development Policy
(2) Legal Framework/ Regulations
(3) Commitments
(4) Support to Private Sector
(5) Collaboration with Partners

Finance
(1) Public Support to Initial Investment
(2) Grant/ Loan Guarantees
(3) Equity Participation to PPP
(4) Development Lending
(5) Tax and Fiscal Incentives

Focal Point for Integration

Institution
(1) Development Body
(2) Inter-ministerial Arrangement
(3) Government Staff
(4) Outside Resources
(5) Capable Regulator

Expertise/Information
(1) Technical Study
(2) Resource Survey/ Investigation
(3) Environment and Social
(4) Power Demand and Supply
(5) Industry Trend /Latest Technology

Elements of Roadmap for Geothermal Development

Phase	Phase I Preparation	Phase II Exploration	Phase III Appraisal	Phase IV Production/ Construction	Phase V O & M
Activity/ Analysis	(1)Ongoing pre-feasibility study (2)Pre-scoping for environmental and social considerations (3)Preparation of Action Plan	(1)Infrastructure procurement (2)Bidding for exploration drilling (e.g. slimholes) (3)Supervision of drilling (4)Updating pre-feasibility study	(1)Concession Tender (2)Executing of appraisal drilling (3)Confirmation of final feasibility (4)Debt financing arrangement (5)Financial closure for construction	(1)Procurement of production drilling, field development and power plant (2)Construction supervision (3)Inspection before use (4)Transmission Line dev.	(1)Monitoring of operation (2)Market regulation (3)Monitoring of power supply and demand
Decision Making/ Action Plan	(1)Phase II Planning (Technical, Financial, Legal, Environmental) (2)Fund-arrangement for Slimhole Drilling	(1)Phase III Planning (2)Marketing sounding for private sector participation (3)MOU	(1)Phase IV Planning (2)Government Participation (3)Selection of Developer (4)Various Contracts	(1)Phase V Planning (2)Preparation for Commissioning	(1)Review of Development (2)Consideration of Future Development

添付資料-4　収集資料リスト

Appendix-4 Collected Data/収集資料

Arclus, 1976. Geology and Geochemistry of the alkali basalt – andesite association of Grenada, Lesser Antilles island arc

The Convention on Biological Diversity in Grenada, 2011. Biodiversity Strategy & Action Plan

Geotermica Italiana, 1981. Reconnaissance study of the geothermal resources of the Republic of Grenada: Final Report to Latin American Energy Organization

Global volcanic program, 2015

Government of Grenada, 1949. Forest, Soil and Water Conservation Act

Government of Grenada, 1973. Litter Abatement Act

Government of Grenada, 1986. Fisheries Act

Government of Grenada, 1991. National parks and Protected Areas Act

Government of Grenada, 1995. Solid Waste Management Act No 11

Government of Grenada, 1997. Environmental Levy Act No 5

Government of Grenada, 2001. Waste Management Act No.16

Government of Grenada, 2002. Physical Planning and Development Control Act No.25

Government of Grenada, 2009. The Beach Protection Amendment Act

Government of Grenada, 2011. The National Energy Policy of Grenada – A low Carbon Development Strategy for Grenada, Carriacou and Petite Martinique

Huttrer and Michels, 1993. Final Report Regarding Prefeasibility Studies of the Potential for Geothermal Development in Grenada

Huttrer and Michels, 1995. Potential for Geothermal Development in Grenada, West indies

IRENA, 2012. Grenada Renewables Readiness Assessment

IWRM, 2007. Planning Road Map

Jacobs, 2016a Geothermal resources development roadmap. Conceptual 3*5MWe project at Mount St. Catherine.

Jacobs, 2016b. Grenada geothermal surface exploration. Integrated report: Geology, Geochemistry & Geophysics.

JICA, 2013. カリブ地域における漁民と行政の共同による漁業管理プロジェクト詳細計画策定調

査報告書

JICA, 2014. 中米・カリブ地域省エネルギー分野に係る情報収集・確認調査報告書

JICA, 2015. カリコム諸国再生可能エネルギー・省エネルギー分野情報収集・確認調査報告書

Light & Power Holding Ltd., 2013. Preliminary Assessment of Electricity System Technical & Economic Issues

NREL US, Energy Policy and Sector Analysis in the Caribbean (2010-2011)

Urzua, L., Benavente, O., Brookes, A. and Ussher, G., 2015. Grenada geothermal surface exploration.

OECS Protected Areas and Associated Livelihoods (OPAAL), 2009. Grenada Protected Area System Plan
Groome, 1970.

Truesdell, A.H., 1976. Summary of Section III. Geochemical Techniques in Exploration, Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, 53-79.

Worldwatch Institute, 2015. Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS), Baseline Report and Assessment

添付資料-5 容積法計算方法

This is an authors manuscript version after accepted by Geothermics, before the proofing process. The final version is available on:
http://dx.doi.org/10.1016/j.geothermics.2016.04.011

Improvement of Calculating Formulas for Volumetric Resource Assessment

Shinya TAKAHASHI, Satoshi YOSHIDA

Nippon Koei, Co., Ltd, 1-14-6 Kudan-kita, Chiyoda-ku, Tokyo 102-8539, Japan

TAKAHASHI-SH@n-koei.jp, YOSHIDA-ST@n-koei.jp

ABSTRACT

The USGS volumetric method is used for assessing the electrical capacity of a geothermal reservoir. The calculation formulas include both underground related parameters and above-ground related parameters. While primary variability and uncertainty in this method lay in the underground related parameters, electric capacity calculated is also a function of the above-ground related parameters. Among those parameters, the fluid temperature of the reservoir will be the key parameter for the volumetric method calculation when used with Monte Carlo method, because this temperature is the variable (uncertain) underground related parameter which affects the steam-liquid separation process in the separator - an above-ground related parameter. Conventional calculation methods do not deal with the steam-liquid separation process being affected by fluid temperature as a random variable when used together with Monte Carlo method. In order to fix up this issue, we have derived calculation formulas by introducing "Available Exergy Function", thereby, the fluid-temperature-dependant separation process can be included in the equations together with the fluid temperature as a random variable. This paper presents the electricity capacity calculations formulas that can be used for the volumetric method together with Monte Carlo method. In addition, a comparison is also made between the proposed method and the USGS method. The theoretical background of the proposed formula has eventually proved to be as same as USGS method except for a few parameters adopted.

Keywords: triple point temperature; single flash power plant; steam-liquid separation process at separator; available exergy function; adiabatic heat drop at turbine

1. INTRODUCTION - ISSUES OF THE CALCULATION METHODS BEING AVAILABLE

The USGS (1978) defines the reservoir thermal energy available under a reference temperature by the following equation.

$$q_r = \rho CV(T_r - T_{ref}) \qquad \text{[kJ]} \qquad \text{(Eq. 1)}$$

Where q_r is geothermal energy that is stored in geothermal reservoir and is able to be used under reference temperature conditions, ρC is volumetric specific heat, V is reservoir volume, T_r is reservoir temperature and T_{ref} is reference temperature. It describes that the reference temperature (15 ℃) is the mean annual surface temperature and for simplicity is assumed to be constant for the entire United States. A set of calculation equations are presented, on the basis of the second law of thermodynamics, to estimate electric energy to be converted from geothermal energy available under the reference temperature. Parameters required for the calculation of the electric generation capacity by using the USGS method are summarized below.

Table 1 Classification of Parameters for USGS Method (1978)

A. Underground related parameters	**B.** Above-ground related parameters
a-1. Reservoir volume: V [m^3]	b-1. Reference temperature: T_{ref} [°C]
a-2. Reservoir temperature: T_r [°C]	b-2. Utilization factor: η_u[-]
a-3. Volumetric specific heat: ρC [$kJ/m^3 - K$]	b-3. Plant life: L [sec]
a-4. Recovery factor: R_g [-]	b-4. Plant factor: F [-]

While primary variability and uncertainty in this method lay in the underground related parameters, considerations have also been directed to above-ground related parameters. The USGS method defines 'utilization factor' to convert heat energy to electric energy, giving 0.4 (USGS 1978). It was updated to 0.45 by USGS (2008). USGS (1978) states the given utilization factor is applicable only for the case that the reference temperature is 15 ℃ (the average ambient temperature in the United State) and the condenser temperature is 40 ℃. On the other hand, S. K. Garg and J. Combs (2011) pointed out that the utilization factor depends on both power cycle and the reference temperature; the available work (calculated electric energy) is a strong function of the reference temperature. This suggests that type of power cycle has to be defined to obtain valid results when practicing the volumetric method.

We consider here a single flash condensing power cycle as a typical plant. Electric energy to be generated is calculated by well established calculation processes for turbine-separator-condenser performance in accordance to thermodynamics; the electric energy generated is principally dependent on fluid temperature sent to separator together with separator temperature and condenser temperature; a set of each fixed temperature may be given into the calculation process. However, these conventional calculation methods are not applicable when practicing the volumetric method together with Monte Carlo method because the fluid temperature shall be dealt as a random variable due to its uncertainty and the steam-liquid separation process is a fluid-temperature-dependant process. Calculation equations for the volumetric method need to satisfy those two requirements when used with Monte Carlo method. In order to provide this issue with a solution, we have derived calculation formulas by introducing "Available Exergy Function", thereby, fluid-temperature-dependant separation process can be included in a equation together with the fluid temperature as a random variable for the use with Monte Carlo method.

With the concept above, Takahashi and Yoshida (2015 a, 2015 b) proposed a simplified calculation formula, assuming a single flash condensing power cycle of the separator temperature 151.8 ℃ and condenser temperature 40 ℃; the formula includes fluid temperature as a random variable and the function that reflects the fluid-temperature-dependant steam-liquid separation process;

that can be used with Monte Carlo method. We herein refined the proposed method and expand its application to various combinations of separator and condenser temperatures assuming a single flash condensing power cycle.

Discussions on other important subjects of the underground related parameters are out of the scope of this paper. We believe the proposed equations will provide clearer ideas on the reservoir potential once the underground related parameters are properly defined.

2. SUMMARY OF THE PROPOSED CALCULATION EQUATIONS

The key points of the proposal are described below. A detailed explanation on how the equations have been derived are presented in Chapter 3 for verifications by readers.

1. We placed the "triple point temperature" in the equation-2 for the place of the reference temperature of the equation-1 of USGS (1978). The equation-2 represents the heat energy potentially stored in the geothermal reservoir, whereas the equation-1 defines the heat energy available in the reference temperature condition out of the heat energy potentially stored in a geothermal reservoir. This is because the fluid recovered at well head is sent to the power plant before exposed to any of reference conditions.

2. We adopted the concept of the "exergy" at a single flash condensing cycle by the equation-5 or -6 (adiabatic heat drop) in accordance to thermodynamics. This equation is eventually proved to be the same as the one given by USGS (1978) as the "Available Work" (Chapter-11).

3. We defined the "Available Exergy Function" by the equation-7. This represents the ratio of the exergy at a turbine-generation system against the total heat energy recovered at well head. Inclusion of the function in the calculation formula is the key idea of this paper.

4. By using the Available Exergy Function, the electricity to be generated is given by the equation-10. "Exergy efficiency", instead of "utilization factor", is included in the equation to tie up with the "exergy" adopted. This is the base equation from which approximation equations for application are derived.

5. For the separator temperature of 151.8 ℃ and the condenser temperature of 40 ℃ as an example; an approximation of the Available Exergy Function is given first as cubic polynomial as in the equation-21; this polynomial approximation is further simplified by the equation-23 for practical uses; Exergy efficiency is approximated in the equation-25, -26 based on 189 actual performance data; Electricity to be generated is given by the equation-27.

6. A comparison with USGS method is discussed in Chapter 8 and Chapter 11 for further reference. A discussion on the utilization factor defined by USGS is also given in Chapter-11

2.1 Application

We will first present the sets of equations in Table-2. Thereafter, the explanation is given on how those equations have been derived.

2.1.1 Underground Related Conditions

The underground related parameters listed in Table 1 shall be determined first. We referred to the USGS method (1978) for the definitions and applications of those parameters. For the proposed calculation method, those parameters can be random variables for Monte Carlo method as has been practiced in the past. Much attention and examination shall be directed to the determination of those parameters because primary variability and uncertainty lay in the underground related parameters. Discussions on how to determine those parameters are out of scope of this paper.

2.1.2 Geothermal Fluid Conditions for the Proposed Method

We assume the geothermal fluid is the single phase liquid conditions in the reservoir. This is because "a fluid that is all liquid has a smaller entropy value than a two phase fluid with same enthalpy; thus, the available work (exergy) value assuming liquid water is greater than any two-phase mixture of the same enthalpy and is an appropriate reference condition" (USGS 1978). The enthalpy of the fluid in the reservoir usually decreases when it comes up to the wellhead due to the partial or entire flashing, frictions, gravitational forces and/or others. We, however, assume the fluid enthalpy available at the wellhead should correspond to the enthalpy of the single phase liquid in the reservoir. The loss of enthalpy while the fluid comes up to the well head could be included in the recovery factor when practicing the volumetric method.

2.1.3 Above-Ground Conditions for the Proposed Method

A single flash condensing system is assumed, where separator temperature and condenser temperature shall be pre-determined. The combination of separator temperature and the condenser temperature will be the index for selection of the simplified calculation equation presented in Table 2. Discussions on how to determine the separator temperature and the condenser temperature in relation to geothermal fluid characteristics are out of the scope of this paper. The following presentation however may be helpful.

Figure 1 shows the relative power output to be generated by a power plant with the separator pressures ranging from 2 bar-a to 10 bar-a, with two cases of condenser temperatures of T_{cd} =40℃ or T_{cd} =50℃, for the geothermal fluid temperature raging from 200 ℃ to 350 ℃, (assuming $R_g \rho CV$=1 for the calculations of relative outputs). Power output may be maximum when the separator pressure of 5 or 6 bar-a for the fluid temperature of 250 ℃ - 275 ℃. These separator pressures may be recommended for an initial stage of resource evaluation if other conditions should allow to do so. Note that power output will be about 88 % when condenser temperature increases from 40 ℃ to 50 ℃ with the separator pressure of 5 bar-a just for a reference.

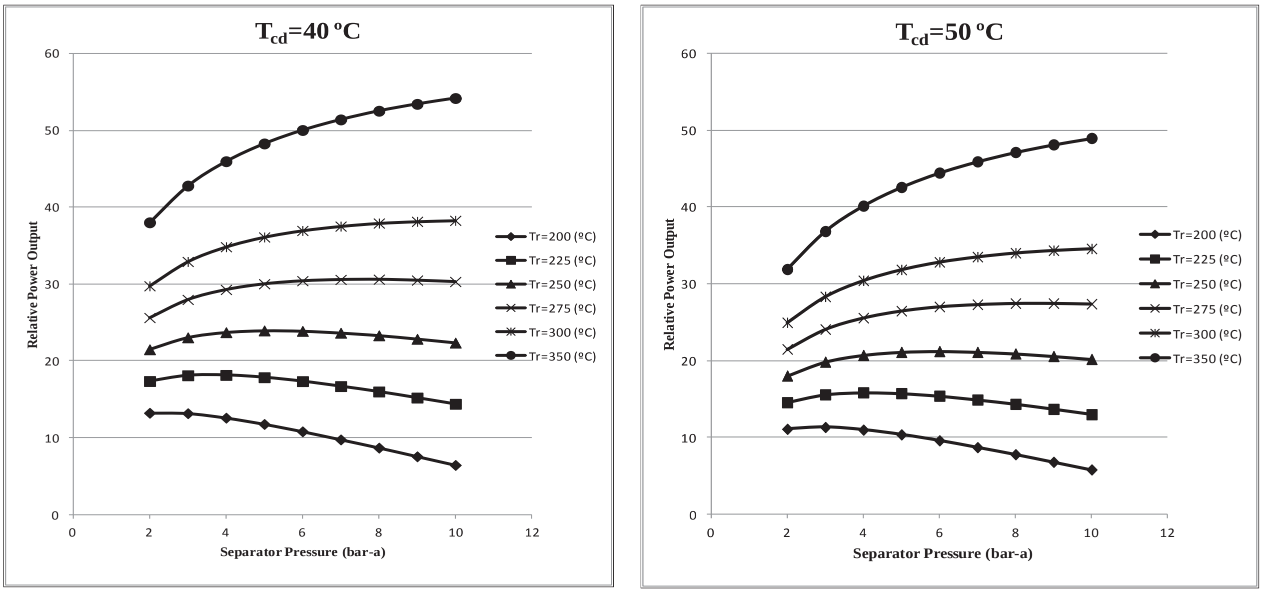


Figure 1 Relative Power Output for Various T_{sp} with T_{cd} =40 ℃ (Left) or T_{cd} =50 ℃ (Right)

2.1.4 A Note on "Reference Temperature" and "Utilization Factor"

For the proposed calculation method, we do not use such generalized temperature names as "reference temperature", "abandonment temperature" or "rejection temperature". Instead, specified temperatures as "triple point temperature", "separator temperature" and "condenser temperature" are used to avoid possible misunderstandings. We do not use 'utilization factor' either, because it is originally defined for the use exclusively in the United State. It is a rather region specific factor. Instead of the "utilization factor", we use plant specific "exergy efficiency" (defined by Equation-24) together with plant specific "exergy" (defined by Equation-5 or -6) at a turbine-generator. A brief observation on the "utilization factor" is given in Chapter 11.1 of this paper for further observation.

2.2 Calculation Equations

The sets of the calculation equations are presented in Table-2. Abbreviations appeared in the table are shown below.

E : Electric energy $[kJ]$
R_g : Recovery factor [-]
V : Reservoir volume$[m^3]$
T_r : Average reservoir temperature [℃]

$\rho C = (1-\varphi)C_r\rho_r + \varphi C_f\rho_f$: Reservoir volumetric specific heat $[\mathrm{kJ}/m^3 - \mathrm{K}]$
φ : Porosity [-]
C_r : Specific heat of rock $[kJ/kg]$
ρ_r : Rock density $[kg/m^3]$
C_f: Specific heat of fluid $[kJ/kg]$
ρ_f: Fluid density $[kg/m^3]$

A calculation equation is uniquely given by selecting a combination of the temperatures of the separator and the condenser. Numerical constants in the equations in Table-2 shall not be modified or changed in any case. These are the products from a series of approximation processes. Coefficients of the turbine-generator efficiency are included in the numerical terms in the equations based on information of actual power plants all over the world.

The average output capacity of the power plant in a designed plant life period is given as follows.

$$W_e = \mathrm{E}/(\mathrm{FL}) \qquad [kJ] \text{ or } [kW]$$

Where; "We" is the average output capacity of the power plant, "F" is the plant utilization factor, "L" is the plant life period (sec).

Table 2 Proposed Calculation Equations for Volumetric Method

Eq.-ID	Conditions				Electric Energy (kJ) Linear Approximation
	Separator		Condenser		
	P (bar-a)	T (℃)	P (bar-a)	T(℃)	
230	2	120.2	0.04	30	(0.19 ± 0.01) * $R_g\rho CV$ * (T_r - 120.2)
240	2	120.2	0.07	40	(0.17 ± 0.01) * $R_g\rho CV$ * (T_r - 120.2)
250	2	120.2	0.12	50	(0.14 ± 0.01) * $R_g\rho CV$ * (T_r - 120.2)
260	2	120.2	0.20	60	(0.11 ± 0.01) * $R_g\rho CV$ * (T_r - 120.2)
370	2	120.2	0.31	70	(0.09 ± 0.01) * $R_g\rho CV$ * (T_r - 120.2)
330	3	133.5	0.04	30	(0.23 ± 0.01) * $R_g\rho CV$ * (T_r - 133.5)
340	3	133.5	0.07	40	(0.20 ± 0.01) * $R_g\rho CV$ * (T_r - 133.5)
350	3	133.5	0.12	50	(0.17 ± 0.01) * $R_g\rho CV$ * (T_r - 133.5)
360	3	133.5	0.20	60	(0.14 ± 0.01) * $R_g\rho CV$ * (T_r - 133.5)
370	3	133.5	0.31	70	(0.12 ± 0.01) * $R_g\rho CV$ * (T_r - 133.5)
430	4	143.6	0.04	30	(0.25 ± 0.02) * $R_g\rho CV$ * (T_r - 143.6)
440	4	143.6	0.07	40	(0.22 ± 0.01) * $R_g\rho CV$ * (T_r - 143.6)
450	4	143.6	0.12	50	(0.19 ± 0.01) * $R_g\rho CV$ * (T_r - 143.6)
460	4	143.6	0.20	60	(0.17 ± 0.01) * $R_g\rho CV$ * (T_r - 143.6)
470	4	143.6	0.31	70	(0.14 ± 0.01) * $R_g\rho CV$ * (T_r - 143.6)
530	5	151.8	0.04	30	(0.27 ± 0.02) * $R_g\rho CV$ * (T_r - 151.8)
540	5	151.8	0.07	40	(0.24 ± 0.02) * $R_g\rho CV$ * (T_r - 151.8)
550	5	151.8	0.12	50	(0.21 ± 0.01) * $R_g\rho CV$ * (T_r - 151.8)
560	5	151.8	0.20	60	(0.19 ± 0.01) * $R_g\rho CV$ * (T_r - 151.8)
570	5	151.8	0.31	70	(0.16 ± 0.01) * $R_g\rho CV$ * (T_r - 151.8)
630	6	158.8	0.04	30	(0.29 ± 0.02) * $R_g\rho CV$ * (T_r - 158.8)
640	6	158.8	0.07	40	(0.26 ± 0.02) * $R_g\rho CV$ * (T_r - 158.8)
650	6	158.8	0.12	50	(0.23 ± 0.02) * $R_g\rho CV$ * (T_r - 158.8)
660	6	158.8	0.20	60	(0.20 ± 0.01) * $R_g\rho CV$ * (T_r - 158.8)
670	6	158.8	0.31	70	(0.18 ± 0.01) * $R_g\rho CV$ * (T_r - 158.8)
730	7	165.0	0.04	30	(0.31 ± 0.02) * $R_g\rho CV$ * (T_r - 165.0)
740	7	165.0	0.07	40	(0.28 ± 0.02) * $R_g\rho CV$ * (T_r - 165.0)
750	7	165.0	0.12	50	(0.25 ± 0.02) * $R_g\rho CV$ * (T_r - 165.0)
760	7	165.0	0.20	60	(0.22 ± 0.01) * $R_g\rho CV$ * (T_r - 165.0)
770	7	165.0	0.31	70	(0.19 ± 0.01) * $R_g\rho CV$ * (T_r - 165.0)
830	8	170.4	0.04	30	(0.32 ± 0.02) * $R_g\rho CV$ * (T_r - 170.4)
840	8	170.4	0.07	40	(0.29 ± 0.02) * $R_g\rho CV$ * (T_r - 170.4)
850	8	170.4	0.12	50	(0.26 ± 0.02) * $R_g\rho CV$ * (T_r - 170.4)
860	8	170.4	0.20	60	(0.23 ± 0.02) * $R_g\rho CV$ * (T_r - 170.4)
870	8	170.4	0.31	70	(0.21 ± 0.01) * $R_g\rho CV$ * (T_r - 170.4)
930	9	175.4	0.04	30	(0.34 ± 0.02) * $R_g\rho CV$ * (T_r - 175.4)
940	9	175.4	0.07	40	(0.31 ± 0.02) * $R_g\rho CV$ * (T_r - 175.4)
950	9	175.4	0.12	50	(0.28 ± 0.02) * $R_g\rho CV$ * (T_r - 175.4)
960	9	175.4	0.20	60	(0.25 ± 0.02) * $R_g\rho CV$ * (T_r - 175.4)
970	9	175.4	0.31	70	(0.22 ± 0.01) * $R_g\rho CV$ * (T_r - 175.4)
1030	10	179.9	0.04	30	(0.35 ± 0.02) * $R_g\rho CV$ * (T_r - 179.9)
1040	10	179.9	0.07	40	(0.32 ± 0.02) * $R_g\rho CV$ * (T_r - 179.9)
1050	10	179.9	0.12	50	(0.29 ± 0.02) * $R_g\rho CV$ * (T_r - 179.9)
1060	10	179.9	0.20	60	(0.26 ± 0.02) * $R_g\rho CV$ * (T_r - 179.9)
1070	10	179.9	0.31	70	(0.23 ± 0.01) * $R_g\rho CV$ * (T_r - 179.9)

3. DERIVING THE PROPOSED EQUATIONS

We will describe hereunder how the proposed calculation equations have been derived. The key abbreviations used correspond to those in Figure 2.

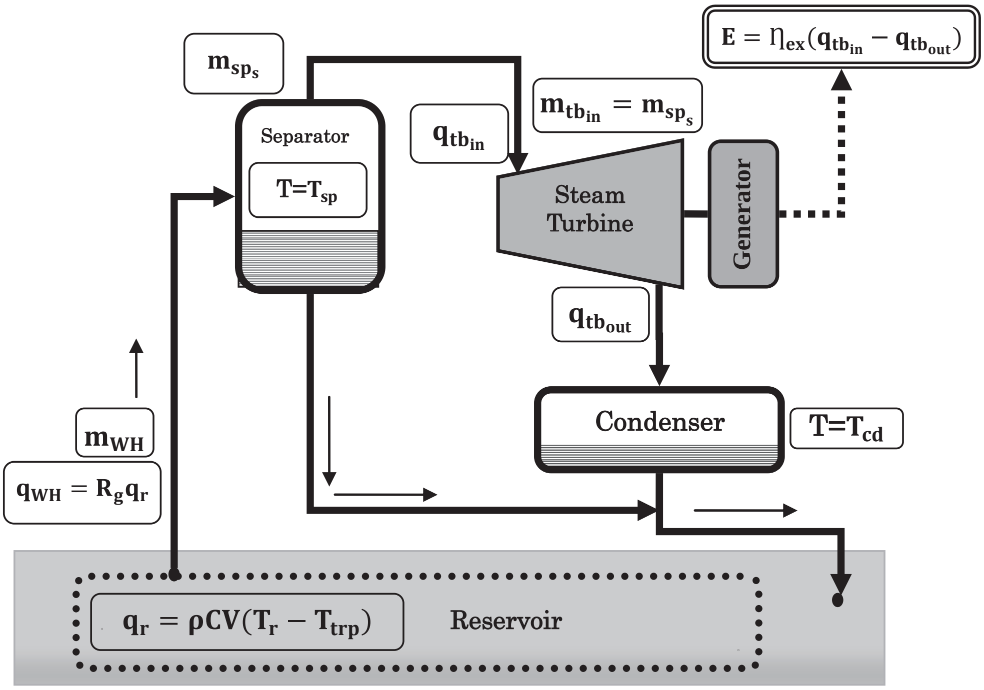


Figure 2 Simplified Single Flash Power Plant Schematic.

3.1 Thermal Energy Potentially Stored in Geothermal Reservoir

The thermal energy potentially stored in a geothermal reservoir is given as follows.

$$q_r = \rho CV(T_r - T_{trp}) \qquad \text{[kJ]} \qquad \text{(Eq. 2)}$$

Where T_{trp} is triple point temperature (T_{trp}=0.01℃ for pure water).

Note that we placed T_{trp} (triple point temperature) in the equation Eq. 2 for the position of T_{ref} (reference temperature) of the equation Eq. 1 given by USGS (1978). The equation-2 represents the heat energy potentially stored in the geothermal reservoir, whereas the equation-1 defines the heat energy available in the reference temperature condition out of the heat energy potentially stored in a geothermal reservoir. The process of utilization of the geothermal fluid stored in a reservoir is made through three steps; (i) First, the geothermal fluid having the heat energy potentially stored in the reservoir is recovered at the well head (with recovery factor to be considered. See section 3.2); (ii) Second, the recovered fluid is sent into a energy utilization system before exposed to any of ambient conditions; (iii) Third, the heat energy, after utilized, decreases down to the final state condition. The equation Eq. 1 represents the heat energy made available through these three steps. Here, we consider the heat energy of the geothermal fluid at the first step only, where the fluid is not yet exposed to any of reference conditions such as the ambient temperature; the geothermal fluid retains potentially available heat energy at this step. In accordance to thermodynamics, potentially available heat energy of geothermal fluid of temperature $\boldsymbol{T_r}$ ºC is given by the equation Eq. 2 using the triple point temperature. The triple point temperature is the extreme minimum temperature for the reference temperature in thermodynamic. The potentially available heat energy is sent into the geothermal power plant.

3.2 Thermal Energy in the Reservoir, Recovery Factor

Since not all heat energy is recovered, the recovery factor is defined by USGS (1978) as follows.

$$R_g = q_{WH}/q_r \qquad \text{[-]} \qquad \text{(Eq. 3)}$$

Where R_g is the recovery factor, and q_{WH} is the heat energy recovered at the well head.

From the equations Eq. 2 and Eq. 3, the heat energy recovered at the well head is expressed by the following equation.

$$q_{WH} = R_g \rho CV(T_r - T_{trp}) \qquad \text{[kJ]} \qquad \text{(Eq. 4)}$$

This recovered heat energy is sent into separator through a adiabatic treated fluid transport pipe system without losing its energy to the ambient.

3.3 Electric Power Output from Turbine-generator

Electric power output generated by a steam turbine-generator system is expressed by the following equation using "adiabatic heat drop" between the heats at the turbine entrance and at the turbine exit (DiPippo 2008 or Hirata, et al 2008 or other references on thermodynamics).

$$E = \eta_{ex}\, m_{tb_{in}} (h_{tb_{in}} - h_{tb_{out}}) \quad \text{[kJ]} \quad \textbf{(Eq. 5)}$$

or

$$E = \eta_{ex} (q_{tb_{in}} - q_{tb_{out}}) \quad \text{[kJ]} \quad \textbf{(Eq. 6)}$$

Where η_{ex} is the turbine-generator efficiency (exergy efficiency), $m_{tb_{in}}$ is the mass of the steam at turbine entrance, $h_{tb_{in}}$ is the specific enthalpy at the turbine entrance, $h_{tb_{out}}$ is the specific enthalpy at the turbine exit, $q_{tb_{in}}$ is the thermal energy of the turbine entrance, $q_{tb_{out}}$ is the thermal energy of the turbine exit.

Note that the $h_{tb_{out}}$ is the heat energy at turbine exit under the condition when the heat at turbine entrance and heat at condenser (final state) are given, the explanation for this will be given in section 4.2.2; that the η_{ex} defined as the turbine-generator efficiency (exergy efficiency) is different from the 'utilization factor' defined by the USGS (1978). Also note that E defined by Eq. 5 is eventually proved to be the exergy energy (Available work) defined by USGS (1978) in Section 11 of the paper.

3.4 Definition of Available Exergy Function

We herein define the following equation. We name it "Available Exergy Function"

$$\zeta = (q_{tb_{in}} - q_{tb_{out}})/q_{WH} \quad \textbf{[-]} \quad \textbf{(Eq. 7)}$$

Where ζ is the Available Exergy Function.

This is the ratio of the heat energy that contributes to electric power generation (i.e. exergy) at the turbine-generator against the whole thermal energy recovered at the well head.

3.5 Deriving the Rational Calculation Equation

We reform the equation Eq. 7 to the following equation.

$$(q_{tb_{in}} - q_{tb_{out}}) = \zeta\, q_{WH} \quad \textbf{[kJ]} \quad \textbf{(Eq. 8)}$$

Combination of the equation Eq. 6 and Eq. 8 gives the following equation.

$$E = \eta_{ex}\, \zeta\, q_{WH} \quad \textbf{[kJ]} \quad \textbf{(Eq. 9)}$$

Further, q_{WH} in the equation Eq. 9 is replaced with the equation Eq. 4, resulting in the following equation.

$$E = \eta_{ex}\, \zeta\, \rho CV (T_r - T_{trp}) \quad \textbf{[kJ]} \quad \textbf{(Eq. 10)}$$

The equation Eq. 10 expresses the electric energy generated at a turbine-generator; the electric energy converted from the thermal energy sent into the turbine-generator of the efficiency η_{ex} (exergy efficiency).

4 CALCULATION OF THE AVAILABLE EXERGY FUNCTION

Although the equation Eq. 10 gives the electric energy to be converted from the thermal energy recovered at the well head, the equation is not ready for a practical calculation in field. This has to be expressed as an equation that shall be practically and user-friendlily used.

4.1 Assumptions

In order to convert the equation Eq. 10 to a calculable equation, we assume the following three conditions.

a. Geothermal fluid recovered at well head is assumed to have the enthalpy that corresponds to the enthalpy of the single phase liquid stored in the reservoir (as stated in 2.1),
b. Single flash condensing geothermal power plant is assumed for resource evaluation (as stated in 2.1),,
c. Dry steam sent into the turbine and wet steam exhausted from the turbine is assumed.

4.2 Deriving the Calculable Equation of "Available Exergy Function ζ"

The Available Exergy Function consists of thermal energies (i) at the well head, (ii) at the turbine entrance and (iii) at the turbine exit. Calculation processes of these three thermal energies are explained hereunder step by step.

4.2.1 Geothermal energy recovered at the wellhead (q_{WH})

The geothermal energy at the well head is expressed by the following equation[1].

$$q_{WH_L} = m_{WH_L}\, h_{WH_L} \quad \textbf{[kJ]} \quad \textbf{(Eq. 11)}$$

[1] Note that the equation $m_{WH} = q_{WH}/(h_{WH} - h_{ref})$ given by USGS(1978) is valid only when $h_{ref} = 0$.

Where q_{WH_L} is the geothermal energy recovered at the wellhead, m_{WH_L} is the mass of the liquid recovered at the wellhead, h_{WH_L} is the specific enthalpy of the fluid recovered at the wellhead.

4.2.2 Thermal energy at turbine entrance ($q_{tb_{in}}$)

The geothermal fluid recovered at the well head is sent into the separator, separated into steam fraction and liquid fraction; and the steam fraction (dry steam) only is sent into the turbine. The thermal energy of the dry steam sent into the turbine is first given by the equation Eq. 12 and Eq. 13; the Equations Eq. 12 and Eq. 13 are re-written using water/steam separation ratio (Eq. 14), as the equation Eq. 15 below.

$$q_{tb_{in}} = m_{sp_s} h_{sp_s} \quad \text{[kJ]} \quad \text{(Eq. 12)}$$

$$m_{sp_s} = \alpha_{sp_s} m_{WH_L} \quad \text{[kg]} \quad \text{(Eq. 13)}$$

$$\alpha_{sp_s} = (h_{WH_L} - h_{sp_L})/(h_{sp_s} - h_{sp_L}) \quad \text{[-]} \quad \text{(Eq. 14)}$$

$$q_{tb_{in}} = \alpha_{sp_s} m_{WH_L} h_{sp_s} \quad \text{[kJ]} \quad \text{(Eq. 15)}$$

Where $q_{tb_{in}}$ is the thermal energy sent into the turbine, m_{sp_s} is the mass of the steam fraction separated at the separator and sent into the turbine, h_{sp_s} is the specific enthalpy of the steam fraction separated at the separator and sent in to the turbine, α_{sp_s} is the ratio of the steam mass fraction separated at the separator, h_{sp_L} is the specific enthalpy of the liquid fraction separated at the separator.

4.2.3 Thermal energy at turbine exit ($q_{tb_{out}}$)

The dry steam sent into the turbine is losing its thermal energy being converted into electric energy. At the same time the dry steam is becoming to be wet steam. The thermal energy of the wet steam exhausted at the turbine exit is given in the following equation. Note the mass of the steam fraction at the turbine entrance is preserved at the turbine exit.

$$q_{tb_{out}} = m_{sp_s} h_{tb_{out_{SL}}} \quad \text{[kJ]} \quad \text{(Eq. 16)}$$

Where $q_{tb_{out}}$ is the thermal energy at the turbine exit, $h_{tb_{out_{SL}}}$ is the specific enthalpy of the wet steam fraction at the turbine exit.

Dryness of the steam exhausted at the turbine exit is given by the following equation (DiPippo 2008 and/or Hirata et. al 2008).

$$\chi = (s_{sp_s} - s_{cd_L})/(s_{cd_s} - s_{cd_L}) \quad \text{[-]} \quad \text{(Eq. 17)}$$

Where χ is the quality of steam (dryness of steam), s_{sp_s} is the entropy of the steam at the separator, s_{cd_L} is the entropy of the liquid at the condenser and s_{cd_s} is the entropy of the steam at the condenser. Using the equation E. 17, the specific enthalpy of the wet steam fraction exhausted at the turbine exit is given by the following equation.

$$h_{tb_{out_{SL}}} = h_{cd_L} + (h_{cd_s} - h_{cd_L})\chi \quad \text{[kJ/kg]} \quad \text{(Eq. 18)}$$

Where h_{cd_L} is the specific enthalpy of the liquid at the condenser and h_{cd_s} is the specific enthalpy of the steam at the condenser.

Combination of the equations Eq. 16, Eq. 17 and Eq. 18 gives the following equation.

$$q_{tb_{out}} = \alpha_{sp_s} m_{WH_L} h_{tb_{out_{SL}}} \quad \text{[kJ]} \quad \text{(Eq. 19)}$$

4.2.4 The Available Exergy Function (ζ)

Replacing the terms in the equation Eq. 7 (Available Exergy Function) with the equations Eq. 11, Eq. 15 and Eq. 19 gives the following equation.

$$\zeta = \alpha_{sp_s}(h_{sp_s} - h_{tb_{out_{SL}}})/h_{WH_L} \quad \text{[-]} \quad \text{(Eq. 20)}$$

An approximation equation of the Available Exergy Function will be derived by the equation Eq. 20 through specifying the combination of a separator temperature and a condenser temperature.

5 APPROXIMATION EQUATION (AN EXAMPLE) OF AVAILABLE EXERGY FUNCTION

5.1 Step One Approximation to Cubic Polynomial

In order to convert "Available Exergy Function" into a calculable equation, a set of a separator temperature and a condenser temperature has to be selected first. There are a number of combinations of the temperatures; among those one sample approximation equation is derived assuming a typical temperature combination.

a. Separator temperature : 151.8℃ (0.5 MPa)
b. Condenser temperature : 40.0℃ (0.007 MPa)

The correlation between the geothermal fluid temperature and the Available Exergy Function is presented in Figure 3 for this example. Figure 3 shows that the thermal energy contributing to electricity power generation in the turbine ranges from 8% to 16 % for the geothermal fluid temperature ranging from 200 ℃ to 300 ℃.

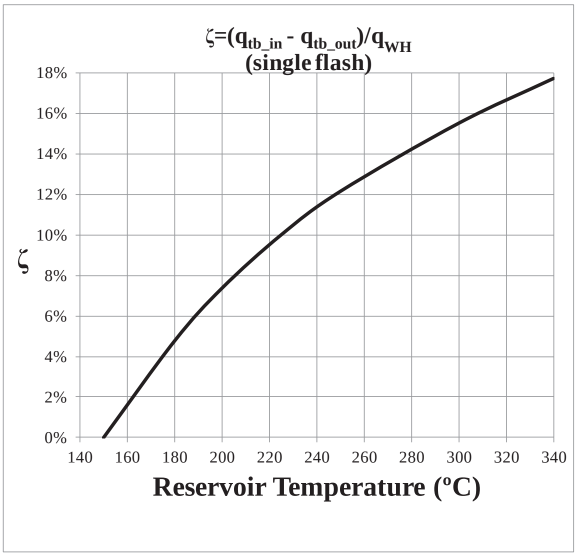


Figure 3 Available Exergy Ratio vs. Fluid Temperature
(for T_{sp}=151.8 ℃, T_{cd}=40.0 ℃)

The approximation equation of the correlation is given by the following cubic polynomial.

$$\zeta = 0.0000000127\,T_r^3 - 0.0000124900\,T_r^2 + 0.0046543806 T_r - 0.4591082158 \qquad \textbf{(Eq. 21)}$$

Note that the Available Exergy Function shall be zero ($\zeta = 0$) when the fluid temperature equals to the separator temperature according to the definition of the equation (see Eq. 7). For this example of the separator temperature T_{sp}=151.8 ℃ , ζ shall theoretically be zero ($\zeta = 0$). (However, this is not necessarily attained by the approximation although we specified ten digits after the decimal point for the coefficients.)

5.2 Step Two Appropriation to a Practical Equation for the Available Exergy Function

The equation Eq.21 as an approximation equation of the Available Exergy Function, is still somewhat too large to be used as a user-friendly calculation equation. Thus, a simpler and more user-friendly approximation equation is hereunder derived.

Figure 4 shows a lenear correlation between $\zeta(T_r - T_{trp})$ in the equation Eq. 10 on the vertical axis and $(T_r - T_{sp})$ on the horizontal axis. Since when $T_r = T_{sp}$, $\zeta = 0$, the correlation between $\zeta(T_r - T_{trp})$ and $(T_r - T_{sp})$ is expressed by the following equation.

$$\zeta(T_r - T_{trp}) = A(T_r - T_{sp}) \qquad [\text{ - }] \qquad \textbf{(Eq. 22)}$$

Where A is a constant.

For this example of T_{sp}= 151.8 ℃ and T_{cd} =40 ℃ the equation Eq. 22 shall be as follows (Figure 4).

$$\zeta(T_r - T_{trp}) = 0.3155(T_r - 151.8) \qquad [\text{ - }] \qquad \textbf{(Eq. 23)}$$

(For T_{sp}= 151.8 ℃ and T_{cd}=40 ℃ only)

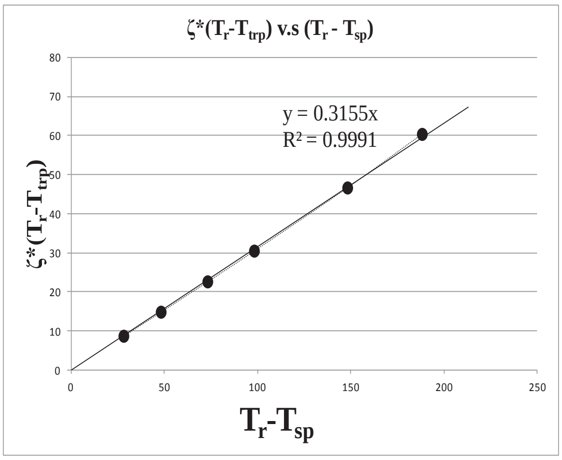


Figure 4 Linear Approximation $\zeta(T_r - T_{trp})$ and $(T_r - T_{sp})$
(for T_{sp}=151.8 ℃, T_{cd}=40.0 ℃)

6 TURBINE-GENERATOR EFFICIENCY (η_{ex})

The equation Eq. 5 defines the electric energy converted from the thermal energy, using the adiabatic heat-drop concept at a turbine. The equation includes the turbine-generator efficiency (exergy efficiency). The equation Eq. 5 is reformed to the following equation.

$$\eta_{ex} = E/\{m_{tb_{in}}(h_{tb_{in}} - h_{tb_{out}})\} \qquad [-] \qquad \text{(Eq. 24)}$$

We analyzed the correlation between turbine-generator efficiencies (η_{ex}), and temperature drops ($T_{tb_{in}} - T_{cd}$) of turbine entrance and condenser. We used 189 data of geothermal power plants all over the world (listed in ENAA 2013 in Japanese) resulting in the following correlation.

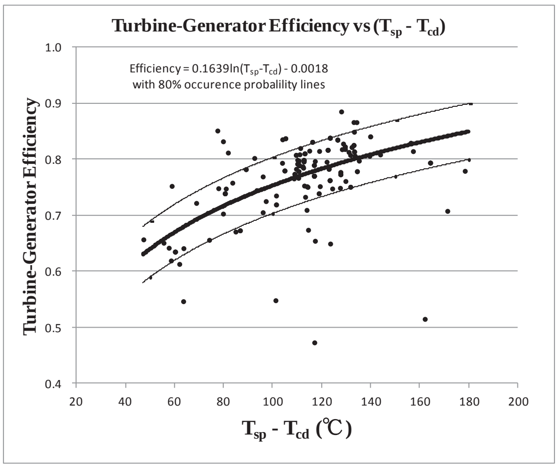


Figure 5 Turbine-Generator Efficiency from 189 data

$$\eta_{ex} = 0.164 \ln(T_{tb_{in}} - T_{cd}) - 0.002 \pm 0.05 \qquad [-] \qquad \text{(Eq. 25)}$$

Where $T_{tb_{in}}$ is the temperature of the turbine entrance and T_{cd} is the temperature of the condenser.

The actual efficiency of a turbine-generator system depends on many factors that include the efficiency of basic power plant design, resource temperature, concentrations of dissolved gases in the reservoir fluid, the condition of plant maintenance and so on. For this reason, we included an range of ± 0.05 in the approximation equation Eq. 25, which encompasses 153 data among the 189 data (approximately 80% occurrence probability).

For this example of T_{sp}= 151.8 °C and T_{cd}=40 °C, the equation Eq. 25 is as follows.

$$\eta_{ex} = 0.77 \pm 0.05 \qquad [-] \qquad \text{(Eq. 26)}$$

(For the case of T_{sp}= 151.8 °C and T_{cd}=40 °C only)

7. A RATIONAL, PRACTICAL AND USER-FRIENDLY EQUATION FOR VOLUMETRIC METHOD

7.1 Approximation For the Example of T_{sp}= 151.8 °C and T_{cd}=40 °C

Replacing $\zeta(T_r - T_{trp})$ and η_{ex} in the equation Eq. 10 with the equations Eq. 23 and Eq. 26 gives the following equation.

$$E = (0.24 \pm 0.02) R_g \rho C V (T_r - 151.8) \qquad [kJ] \qquad \text{(Eq. 27)}$$

(For the case of T_{sp}= 151.8 °C and T_{cd}=40 °C only)

The equation Eq. 27 above gives the electric energy converted in the geothermal power plant with separator of T_{sp}= 151.8 °C and condenser of T_{cd}=40 °C. The other factors, i.e. recovery factor (R_g), Volumetric specific heat of the reservoir (ρC), reservoir volume (V) and average reservoir temperature (T_r) have to be given by the practitioners in charge.

7.2 Approximation Equations for Various Sets of Separator Temperatures and Condenser Temperatures

We have derived approximation equations for various sets of separator temperatures and condenser temperatures, so that practitioners may select one or some of those that may suite to their site conditions. The equations are presented in Table-2.
.

8. A COMPARISON WITH THE USGS METHOD

A comparison is made between the proposed method and the USGS method.

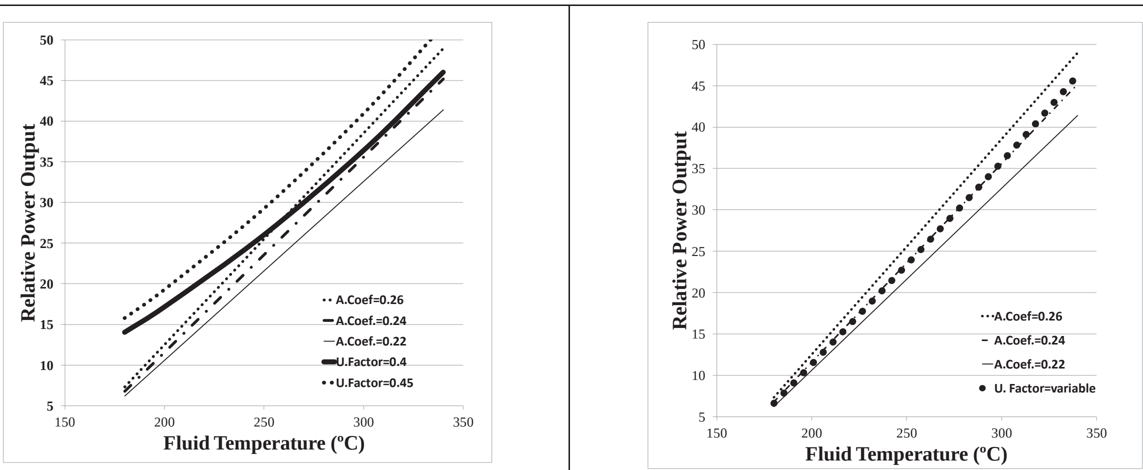
In theory, T_{ref} should be T_{trp} in USGS method when fluid is sent into a geothermal power plant directly. But, here T_{ref} = 15 ℃ is assumed because the utilization factors (0.4 and 0.45) might have been given with the assumption that the T_{ref} is the average ambient temperature of the USGS[2]. The conditions for the comparison is summarized in Table 3.

Table 3 Calculation Conditions for Comparison between USGS method and the Proposed method

	USGS method	Proposed method (for T_{sp} = 151.8 ℃ and T_{cd} = 40 ℃)
Reference Temperature	Ambient temperature (15 ℃)	Triple point temperature for potential heat stored in reservoir (0.01℃)
Separator temperature	Not given	151.8 ℃
Condenser temperature	40 ℃	40 ℃
Factor in equation	Utilization factor (η_u) 0.40, 0.45	Approximation value of Exergy efficiency (η_{ex}) x Available exergy function (ζ) 0.22 (minimum), 0.24 (central value), 0.26 (maximum)
Reservoir related factors	($R_g \rho CV$) = 1 is assumed for this comparison	

Figure 6 (Left) shows that the USGS method gives slightly larger values than those of the proposed method; the USGS method with the utilization factor of 0.4 is in good agreement with the proposed method when fluid temperature is over 250 ℃ approximately.

While the USGS method treated the utilization factor as constant possibly for a practical reason, it shall be variable in theory. The utilization factors as variable is calculated in Section 11.1. We calculated the relative power output using "utilization factors as variable". The relative power output of the USGS method with variable utilization factor is shown in Figure 6 (Right). It demonstrates that the result of the USGS method is on the line of the proposed method with the approximation coefficient of 0.24.



Proposed Method (for $\mathbf{T_{sp}}$=151.8 ℃, $\mathbf{T_{cd}}$=40 °℃) and USGS method (fixed Utilization factor of 0.40 and 0.45, $\mathbf{T_{ref}}$=15 ℃ and $\mathbf{T_{cd}}$=40 ℃)

Proposed Method and USGS method with variable utilization factor (for both $\mathbf{T_{sp}}$ =151.8 ℃, $\mathbf{T_{cd}}$=40 ℃; only for USGS $\mathbf{T_{ref}}$=15 ℃)

Notes: A. Coef.: Approximation Coefficient of the proposed method, U. Factor: Utilization Factor of the USGS method

Figure 6 A Comparison of the Proposed Method with USGS Method

It has become evident that both of the USGS method and the proposed method are on the same theoretical basis (see the section 11.2). The major difference is that the USGS method defines the Utilization factor as a constant, whereas the proposed method deals all factors as dynamic variable factors. Thus, the proposed method is more 'accurate' than the USGS method although the method is expressed by approximation equations. Moreover, the proposed method is much simpler and therefore much more user-friendly, particularly when practiced with Monte Carlo Simulation.

9. NOTES AND DISCUSSIONS

It has been pointed out that the USGS method may have given larger resource estimations than that of reservoir resources actually available on site. Thus, the proposed method may also give excessive resource estimation than actual. In connection with this issue, one may be tempted to calibrate the equations by changing the constants in the equations of the proposed method. However, any of the constants shall not be changed, because the equations in Table-2 do not represent any of thermodynamic implications directly; the separator temperature in the second brackets acts only for zero-point adjustment; the constants in the first brackets are only the resultants of the approximations.

If the calculation results should not agree to the reservoir resource actually available, such reservoir related factors have to be reviewed as recovery factor (R_g), volumetric specific heat of the reservoir (ρC), reservoir volume (V) and average reservoir temperature (T_r). In particular, recovery factor (R_g) and reservoir volume (V) shall have to be examined prudently, because the two factors will give significant impacts on the resource assessment.

10. CONCLUSIONS

The USGS method is widely used for assessing the electrical capacity of a geothermal reservoir. While the under-ground related parameters will have significant impacts on the resource assessment, the electric capacity calculated is a strong function of the above-ground related conditions. The fluid temperature recovered at well head will be the key parameter for the volumetric method calculation when used with Monte Carlo method, because this temperature is the variable (uncertain) underground related parameter which affects the steam-liquid separation process in the separator - an above-ground related parameter. We have derived calculation formulas by introducing "Available Exergy Function", thereby, fluid-temperature-dependant separation process can be included in the equations together with the fluid temperature as a random variable for the Monte Carlo method. It is expected that this calculation method may provide clearer ideas on geothermal resources assessment because the above-ground related parameters are separately defined from the much uncertain underground related parameters. The proposed calculation formulas is proved to be on the same theoretical base of the USGS method (1978). They may thus give larger resource estimation than actually monitored on site if conventional underground related parameters should be selected. However, any of coefficients in the equations of the proposed method must not be changed or adjusted or calibrated. It is the underground related factors that shall be reviewed. In particular, recovery factor and/or reservoir volume have to be reviewed.

11. ADDITIONAL NOTES

11.1 About Utilization Factor of the USGS Method

The utilization factor defined by the USGS (1978) is as follows.

$$\eta_u = E'/W_A \qquad [-] \qquad \text{(Eq. 28)}$$

Where η_u is the utilization factor; W_A is the thermodynamically available energy produced at a thermo-engine, into which all energy of the recovered fluid at well head (originally under the ambient condition in the United State) is assumed to be sent in. E' is the electric power generated at the thermo-engine, into which only the steam fraction separated at the separator is assumed to be sent in.

The USGS has given the constants of 0.40 (USGS 1978) or 0.45 (USGS 2008) to the utilization factor as an empirical factor. However, the factor shall be a variable because W_A and E' are given by the following exergy equations, based on the USGS theoretical concept.

$$W_A = m_{WH_L}\{h_{WH_L} - h_{ref_L} - T^K_{ref_L}(s_{WH_L} - s_{ref_L})\} \qquad [kJ] \qquad \text{(Eq. 29)}$$

$$E' = \eta_{ex} m_{sp_s}\{h_{sp_s} - h_{cd_L} - T^K_{cd_L}(s_{sp_s} - s_{cd_L})\} \qquad [kJ] \qquad \text{(Eq. 30)}$$

Where $T^K_{ref_L}$, $T^K_{cd_L}$ are temperature of liquid in reference (i.e. ambient) condition and the condenser in K (absolute temperature) respectively; h_{ref_L}, h_{cd_L} are specific enthalpy of liquid in reference (i.e. ambient) condition and in the condenser respectively; s_{WH_L}, s_{ref_L} , s_{cd_L} are specific entropy of the liquid at the well head, in reference (i.e. ambient) condition and in the condenser respectively. The numerical utilization factors calculated by the equation Eq. 28, Eq. 29 and Eq. 30 for the case of T_{sp}=151.8 ℃, T_{cd}=40.0 ℃ and η_{ex}=0.77 are as shown in the table below.

Table 4 Utilization Factors as Variable (for T_{sp}=151.8 ℃, T_{cd}=40.0 ℃, η_{ex}=0.77)

Fluid temperature at Well head (℃)	Utilization factor (variable)
200	0.27
250	0.36
300	0.39
340	0.40

The utilization factor ranges from 0.27 to 0.40 in accordance to the temperatures of the fluid recovered at the well head. If the exergy efficiency η_{ex} could be larger than 0.77, the utilization factor would be larger than those calculated above.

11.2 Theoretical Background of the Proposed method

We presented first the adiabatic heat drop concept for the proposed method in the equation Eq. 5. The specific enthalpy of the turbine exit was expressed by the equations Eq. 16, Eq. 17 and Eq. 18. Among those, combination of the equations Eq. 17 and Eq. 18 gives the following equation.

$$h_{tbout_{SL}} = h_{cd_L} + (h_{cd_s} - h_{cd_L})\{(s_{sp_s} - s_{cd_L})/(s_{cd_s} - s_{cd_L})\}$$

$$= h_{cd_L} + T^K_{cd_L}(s_{cd_s} - s_{cd_L})\{(s_{sp_s} - s_{cd_L})/(s_{cd_s} - s_{cd_L})\}$$

$$= h_{cd_L} + T^K_{cd_L}(s_{sp_s} - s_{cd_L}) \qquad [kJ/kg] \qquad \text{(Eq. 31)}$$

Further combination of the equation Eq. 5 and Eq. 31 gives:

$$\mathbf{E} = \eta_{ex} m_{tb_{in}}\{h_{tb_{in}} - h_{cd_L} - T^{K}_{cd_L}(s_{sp_s} - s_{cd_L})\} \quad \text{[kJ]} \quad \text{(Eq. 32)}$$

Where $m_{sp_s}=m_{tb_{in}}$, $h_{sp_s}=h_{tb_{in}}$

The equation Eq. 32 has been derived from the concept of the proposed method (adiabatic heat-drop at turbine), whereas the equation Eq. 30 from the USGS method (exergy exergy). The electric energy outputs of the two methods have become eventually to be expressed by the same equation. Thus, the two methods have been proved to be on the same theoretical basis

12. ACKNOWLEDGMENTS

We would like to express our greatest appreciation to the Japan International Cooperation Agency (JICA), who allows and supports us in conducting this work in courses of JICA financed geothermal development surveys in east African countries. We also would like to express our gratitude to Prof. Hirofumi Muraoka, Daisuke Fukuda and our colleagues working together for helpful discussions and suggestions as well as Nippon Koei Co., Ltd for supporting us to complete this work. We also extend our appreciation to the editor and the reviewers who provided us with suggestive comments that encouraged us to make revisions of this paper. Finally, we would thank the professionals who communicated with us for our previous work (Takahashi and Yoshida 2015a) that is the base of this paper, the names of whom are presented with thanks in the previous work.

REFERENCES

DiPippo, Ronald. *Geothermal Power Plants; Principles, Applications, Case Studies and Environmental Impact, 2nd edition*. Oxford, UK: Elsevier, 2008.

ENAA: Engineering Advncement Association of Japan. *Study on Small Scale Geothermal Power Generation and Cascade Use of Geothermal Energy (in Japanese)*. Tokyo, Japan: Japan Oil Gas and Metals Nationla Corporation, 2013.

Garg, Sabodh, K. and Jim Combs. *A Reexamination of USGS Volumetric "Heat in Place" Method*. Stanford, CA, USA: Proceedings, 36th Workshop on Geothermal Reservoir Engineering, Stanford University, 2011.

Grant, M. A. *Stored-heat assessments: a review in the light of field experience*. Geothe. Energy. Sci,. 2, 49-54, 2014. Germany: Geothermal Energy Science, 2014.

Grant, M. A; Bixley, P, F. *Geothermal Reservoir Engineering second Edition*. Oxford, UK, 359p: ELSEVIER, 2011.

Hirata, T., et al. *Engineering Thermodynamics (in Japanese)*. Tokyo: Mirikita Publishing Co., Ltd, 2008.

Muffler, L. J. P.; Editor. *Assessment of Geothermal Resources of the United States - 1978; Geological Survey Circular 790*. USA: USGS, 1978.

Takahashi, S., Yoshida, S. *A Rational and Practical Calcuration Aproach for Volumetric Method (2)*. Resume for Presentation. Tokyo, Japan: Geothermal Research Society of Japan, 2015b.

Takahashi, S., Yoshida, S.,. *A Rational and Practical Calcutation Approach for Volumetric Method*. Procceedings. Stanford, CA, USA: Stanford University, 2015a.

Williams, Colin F., Marshall J. Reed and Robert H. Mariner. *A Review of Methods Apllied by the U.S. Geological Survey in the Assessment of Identified Geothermal Resources*. USA: Open-FileReport 2008-1296, U.S. DEpartment of the Interior, U.S. Geological Survey, 2008.

*** End of document ***