Why and How Geothermal Energy Works —
Environmental Benefits and Successful Outreach Strategic Plans Worldwide

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2018/05/18 (Fri.)

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Department of Earth Sciences
and Institute of Applied Geology

Outline

Solution and threshold of climate crisis

Energy Transformation by Renewable Energy

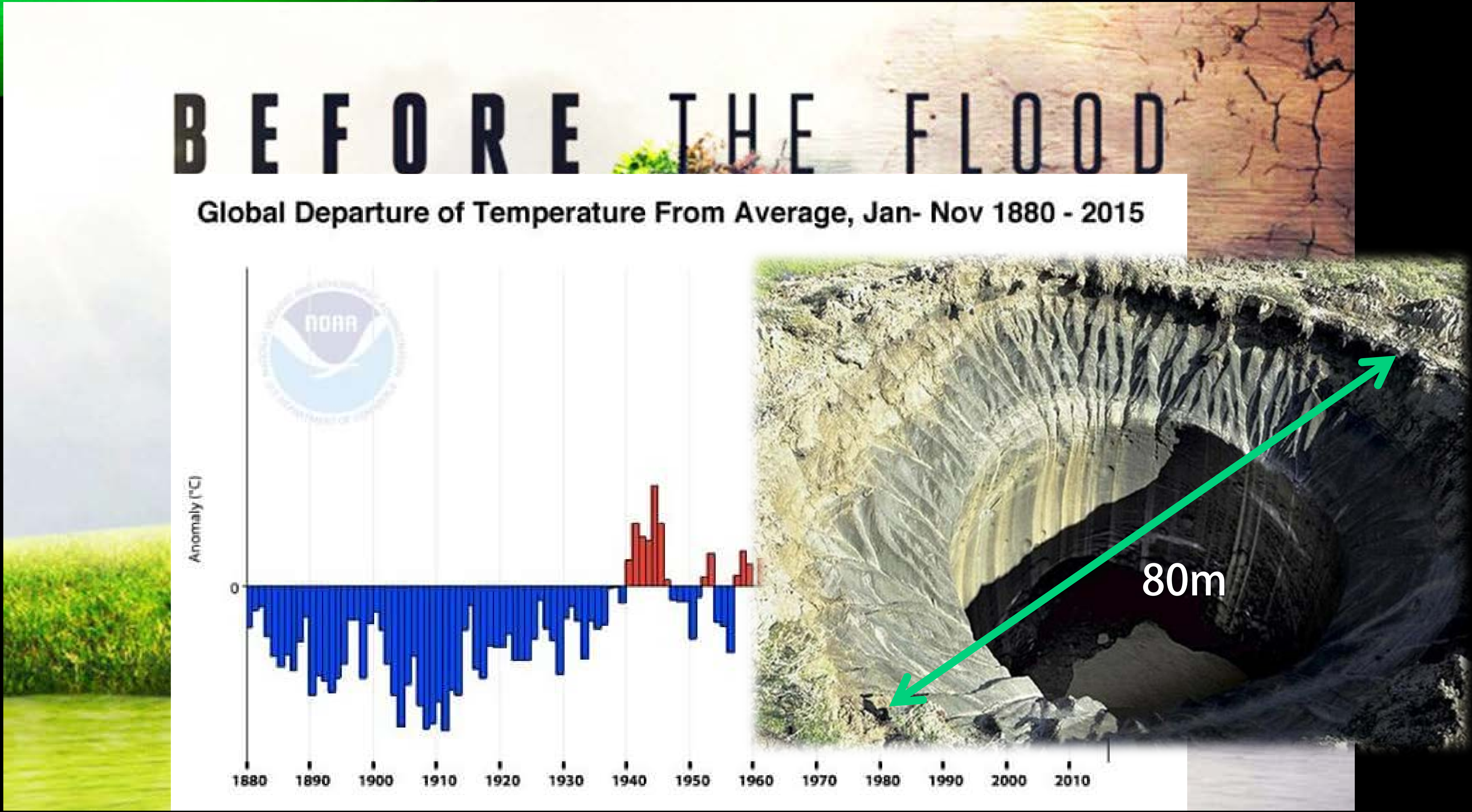
Why Geothermal Energy Promoted by UN

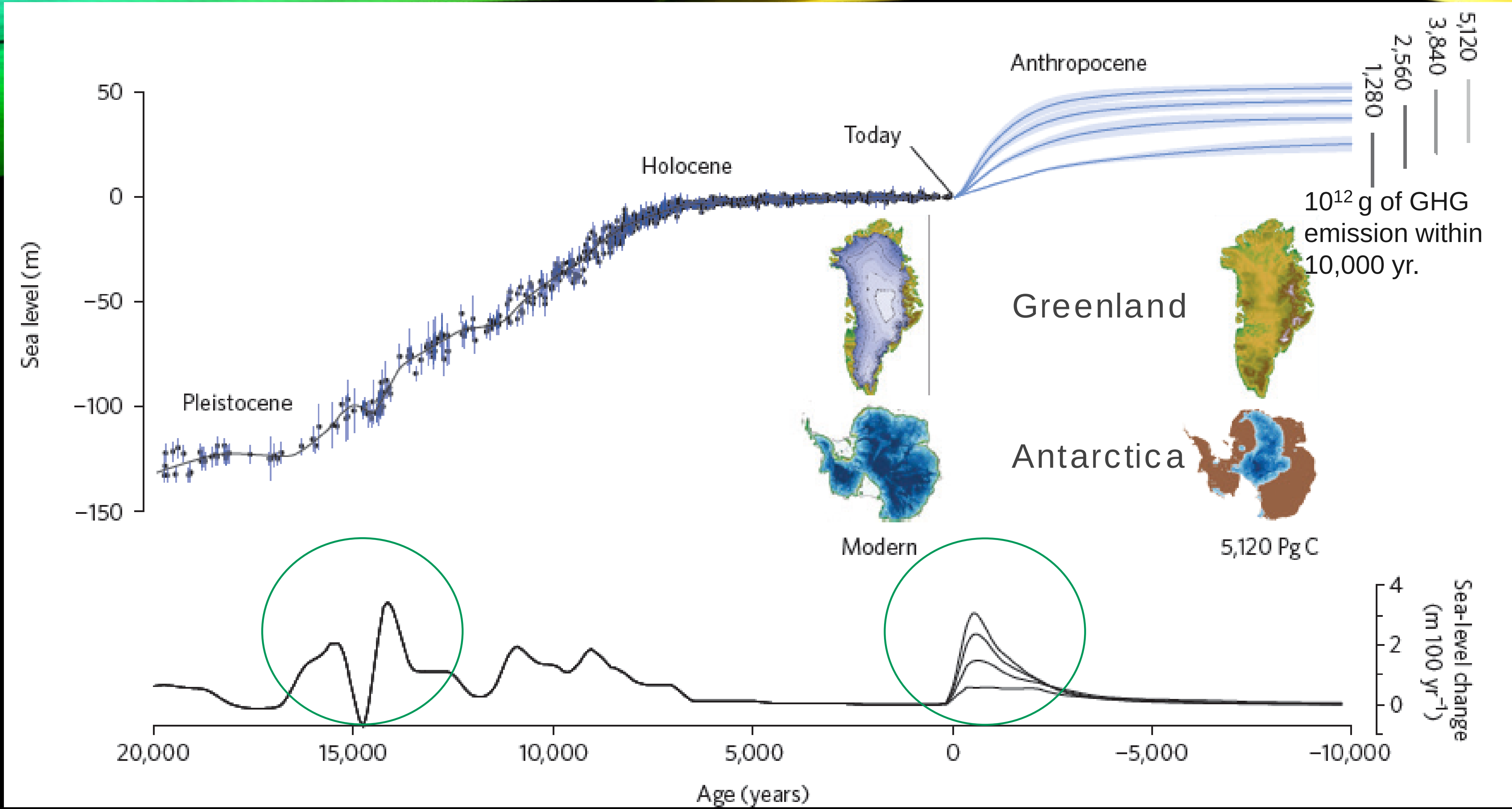
How Geothermal Energy Promoted by UN

Conclusions & What we have done

Solution and threshold of climate crisis

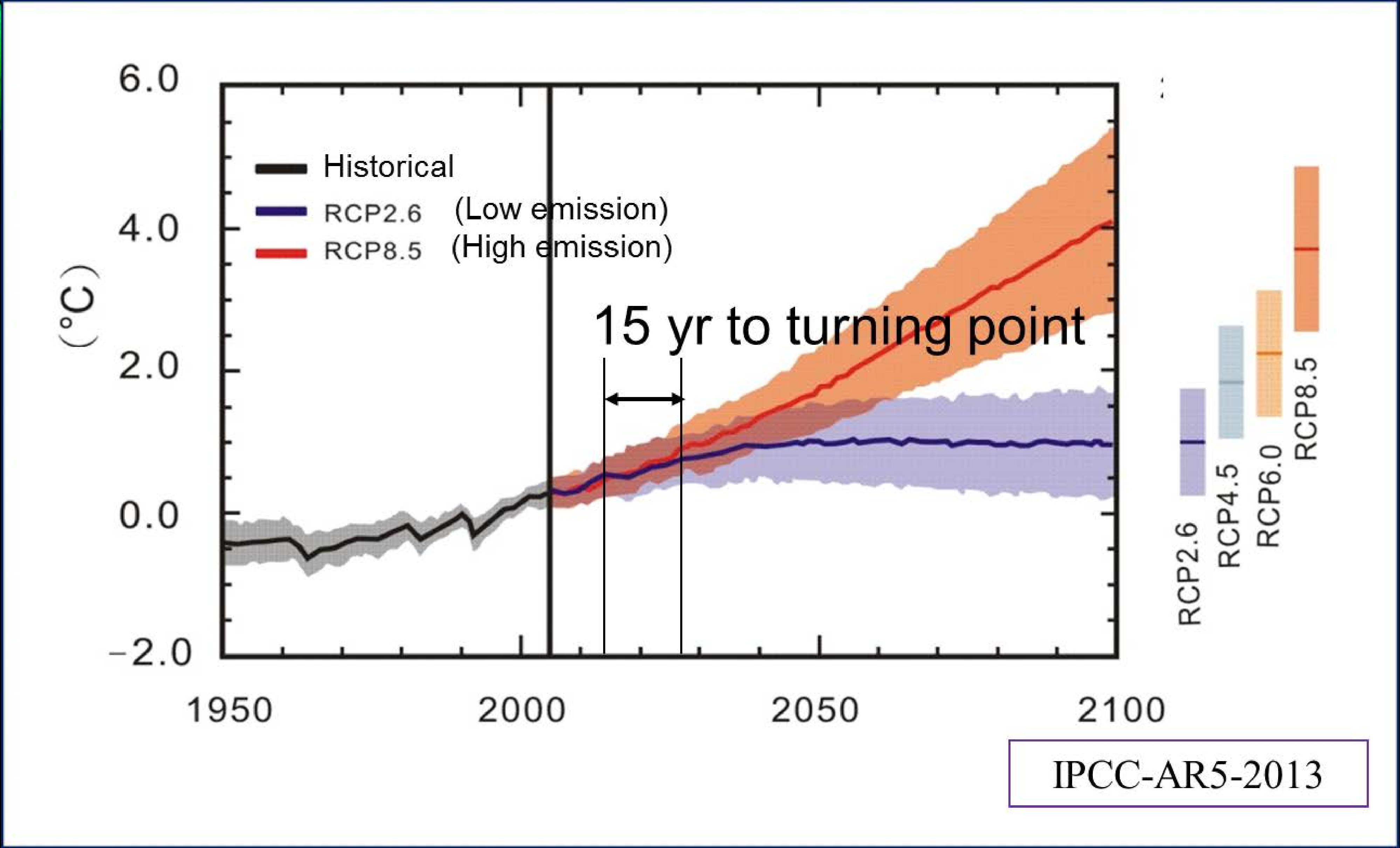
We have no much time left and we are beyond no return


BEFORE THE FLOOD
Global Departure of Temperature From Average, Jan- Nov 1880 - 2015
Anomaly (°C)
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
NOAA
80m



global mean sea-level rise in the past and future

Peter U. Clark et al., 2016 NATURE CLIMATE CHANGE
DOI: 10.1038/NCLIMATE2923



Intergovernmental Panel on Climate Change (IPCC)- The Nobel Peace Prize 2007

News › Science

Climate change escalating so fast it is 'beyond point of no return'

New study rewrites two decades of research and author says we are 'beyond point of no return'

Peter Walker | Friday 2 December 2016 |

18K
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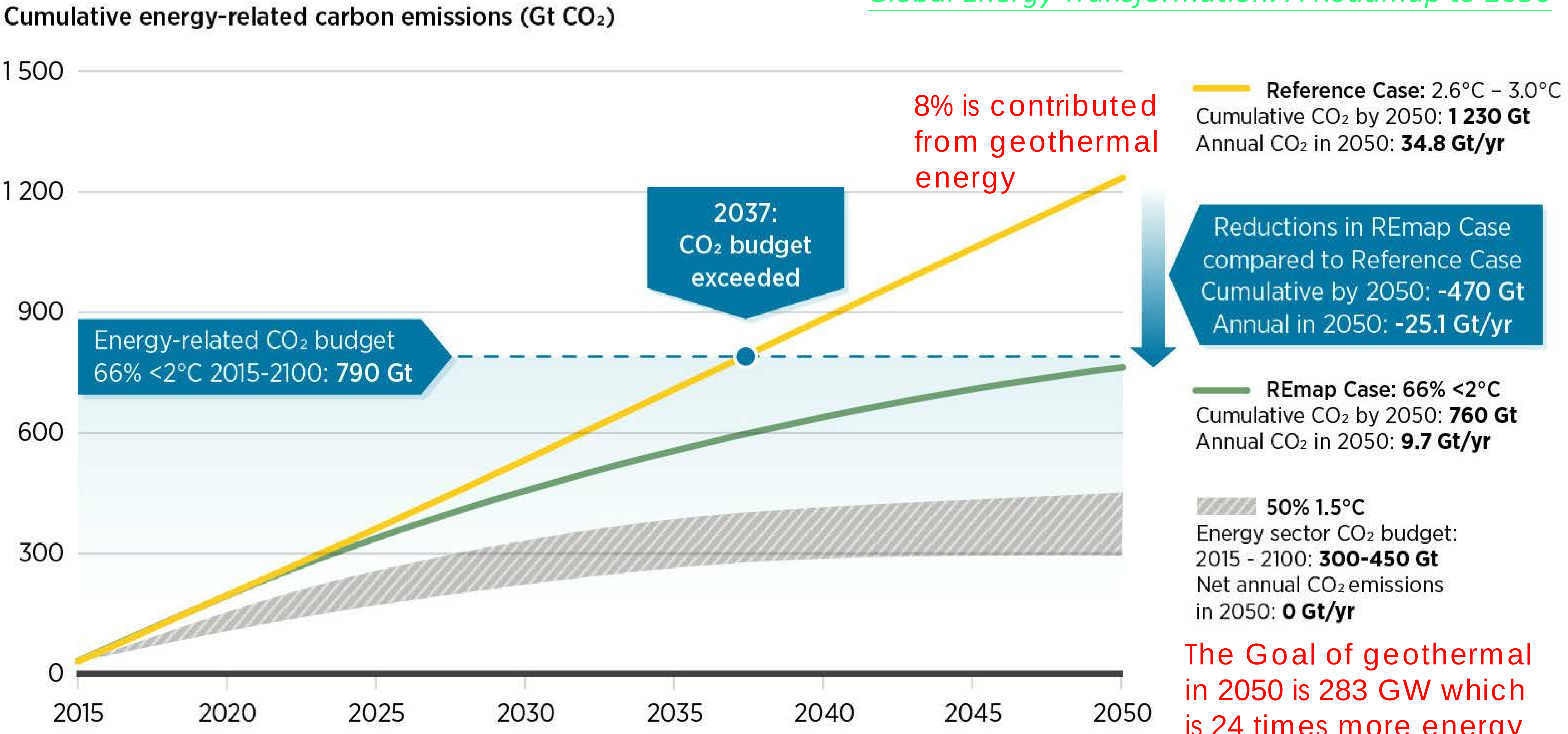
The Independent Onlin

Global Energy Transformation: A Roadmap to 2050

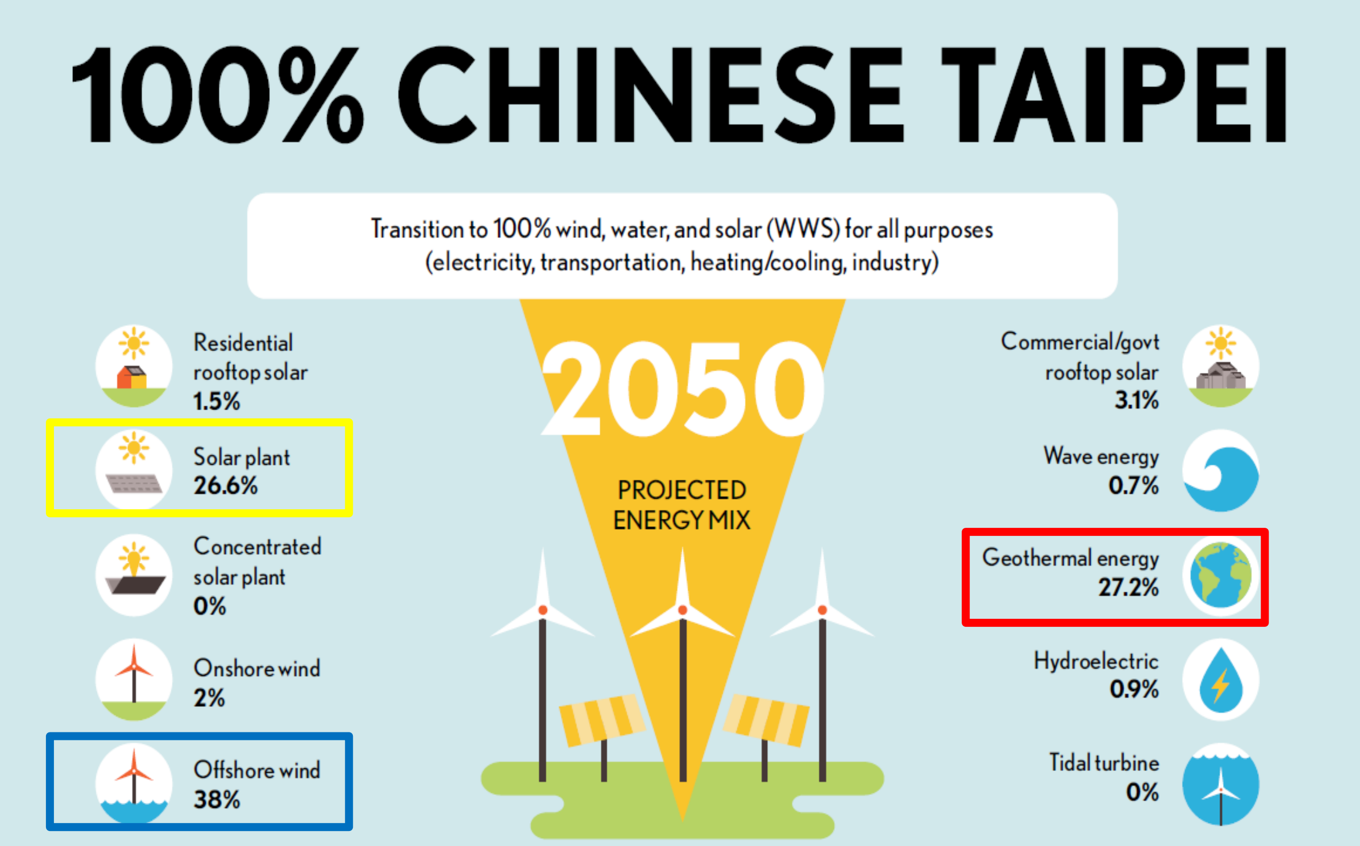


8% is contributed from geothermal energy

The Goal of geothermal in 2050 is 283 GW which is 24 times more energy than now.

Energy Transformation by Renewable Energy

We have no much time left and we are beyond no return



27.2 %
=>30 GW

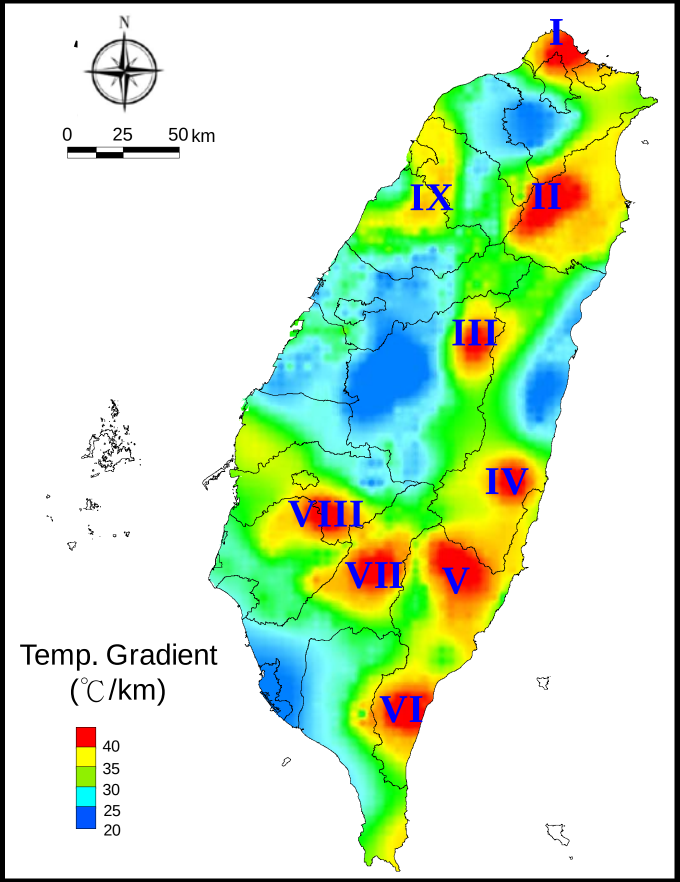
From 139-country 100% Clean and Renewable roadmaps (Jacobson et al., 2015), geothermal energy in Taiwan should reach 3,028 Mwe in 2050, about 27.140%.

Our 「Energy Transformation」 challenge in near future:

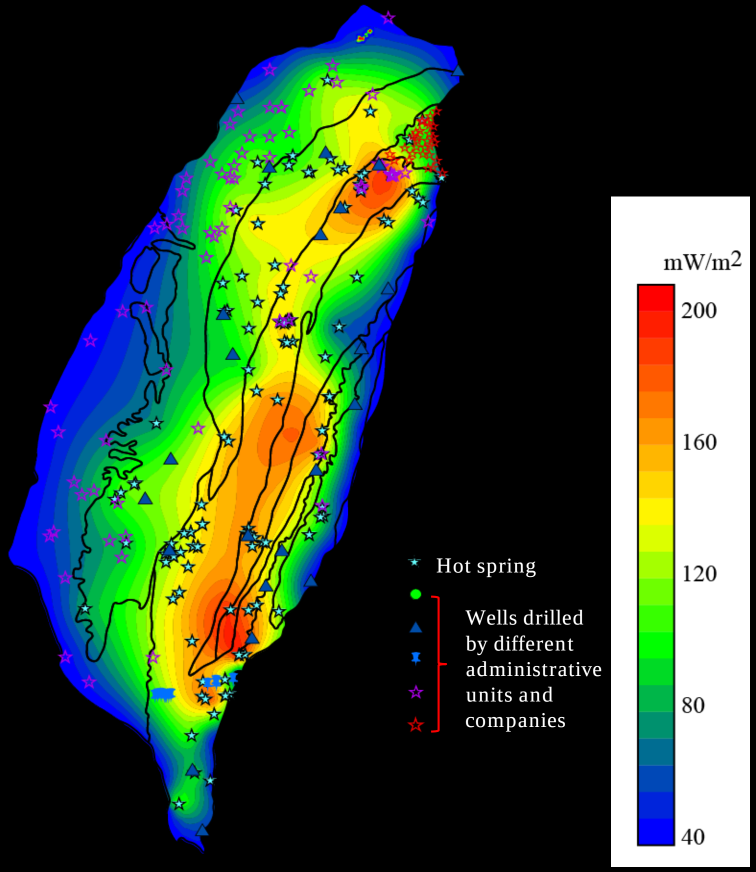
2018→ 2020 → 2050

0 % → 0.293 % → 27.140%

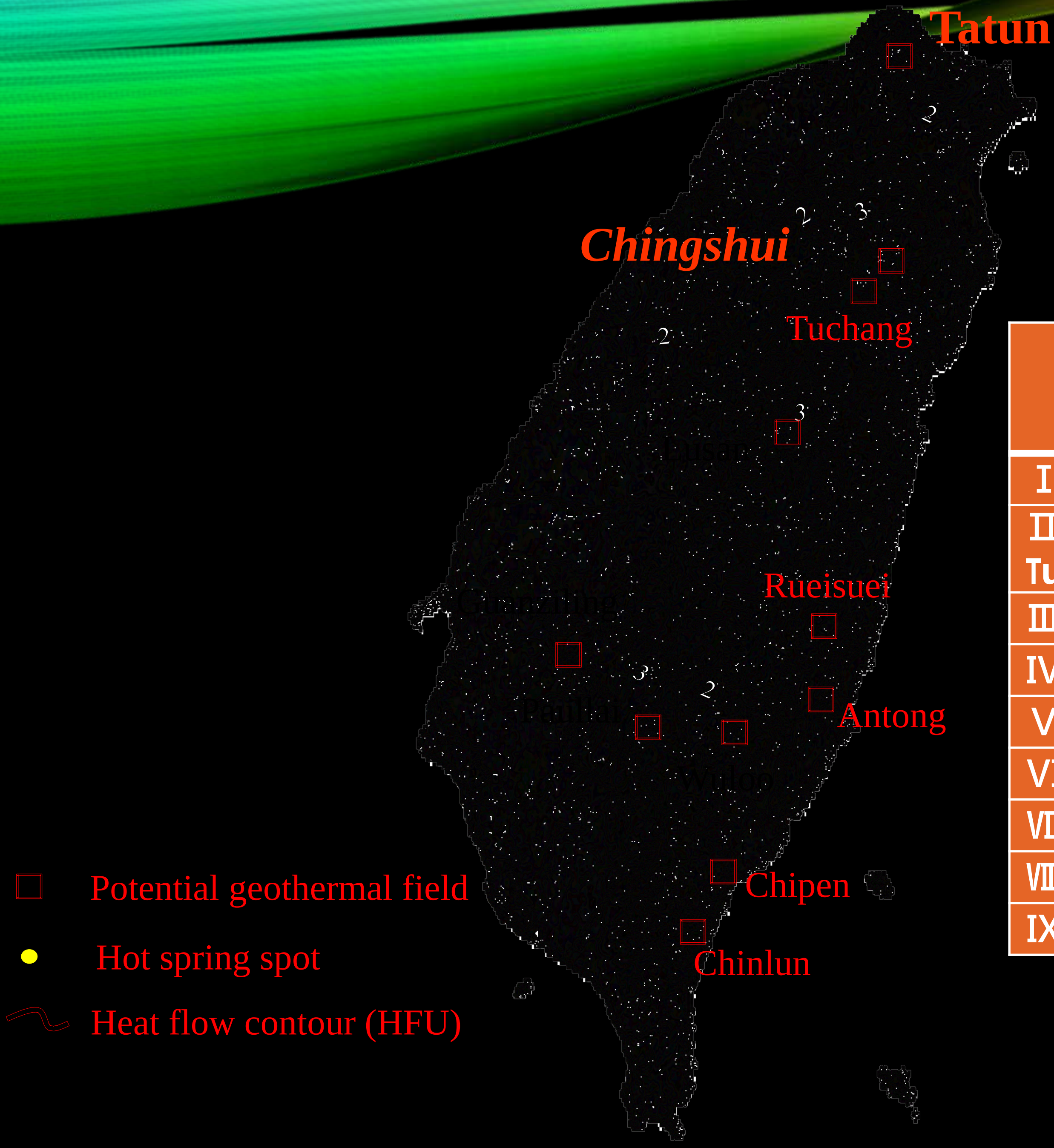
DISTRBUTION OF TAIWAN'S GEOTHERMAL RESOURCES



1.ITRI，2012
2.Store heat method



159.6 Gwe (Frank Yang et al., 2015 WGC)
180 Gwe (Ping-Yu Chang et al, 2013)



Site	Area (km^2)	Temp. (°C)	Geology code	Resource code
Ⅰ Tatun	278	236	3	4~5
Ⅱ Chingshui-Tuchang	909	223	1	3~4
Ⅲ Lushan	279	210	1	3~4
Ⅳ Rueisuei-Antong	467	195	1	3~4
Ⅴ Wuloo	571	196	1	3~4
Ⅵ Chipen-Chinlun	701	214	1	3~4
Ⅶ Paullai	476	205	1	3~4
Ⅷ Guanziling	510	197	4	3~4
Ⅸ Hsinchu- Miaoli	343	192	4	3~4

Geology Code	Geologic type	Resource Code	Resource fluid characteristics	No. of fields	No. of wells
1	Granitic/higher-grade metamorphic	4	Moderate temperature	1	38
		5	High temperature	1	150
2	Tertiary and older volcanic/ volcaniclastic (large-scale volcanic structures absent)	3	Low temperature	5	98
		4	Moderate temperature	4	98
		5	High temperature	1	33
		7	100 percent steam	1	378
3	Younger volcanic/volcani-clastic (large-scale volcanic structures (volcanoes, calde-ras) preserved)	4	Moderate temperature	6	155
		5	High temperature	15	522
		6	Ultra-high temperature	12	539
		7	100 percent steam	2	93
4	Sedimentary basin (clastic, drilled above basement)	3	Low temperature	2	178
		5	High temperature	1	13
		6	Ultra-high temperature	2	257
5	Sedimentary basin (clastic, wells drilled into basement)	2	Very low temperature	1	9
		3	Low temperature	1	8
		4	Moderate	2	4

1) non-electrical grade (<100°C);
2) very low temperature (100°C to <150°C);
3) low temperature (150°C to <190°C);
4) moderate temperature (190°C to <230°C);
5) high temperature (230°C to <300°C);
6) ultra-high temperature (300°C+); and
7) steam field (230°C to 240°C).

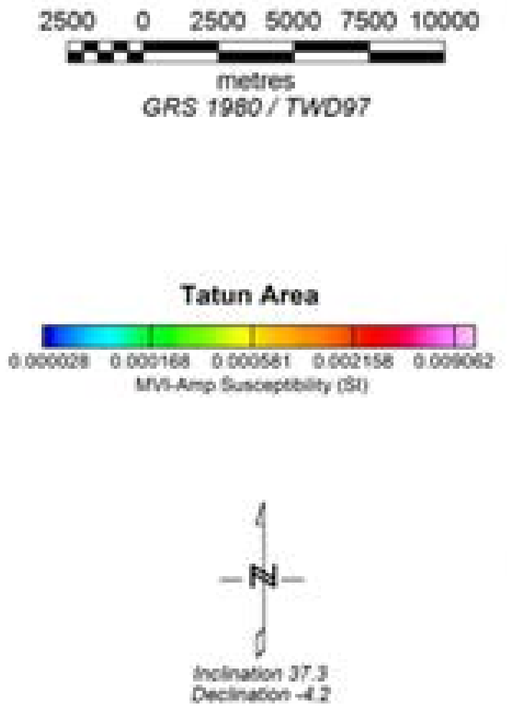
Ref: Sanyal (2005)

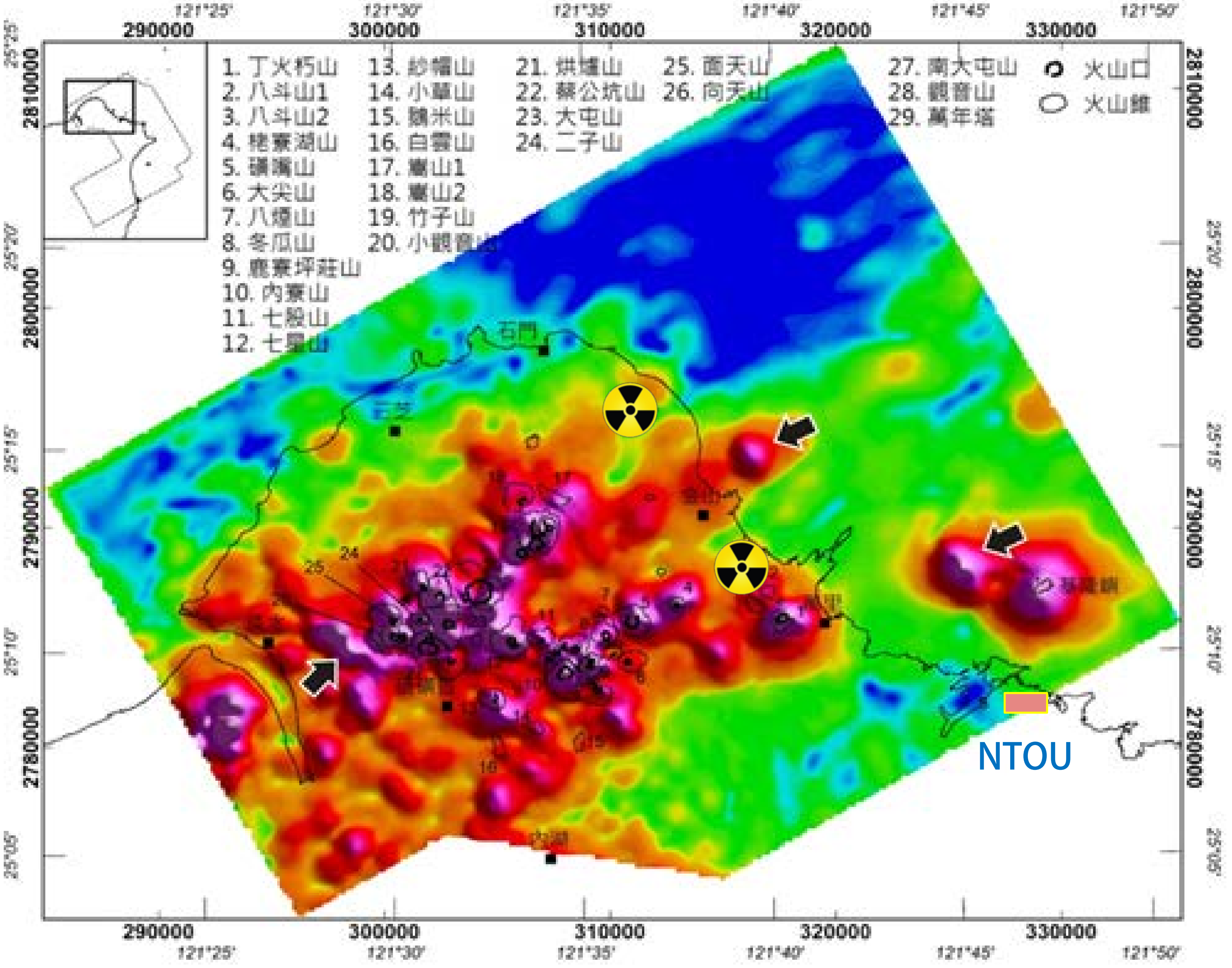
For moderate temperature resource, the production is 3-12 MW per well;
For high temperature resource, the production is 12-25 MW per well.

It is crucial that the combination of enthalpy and resource types are fully assessed before drilling starts.

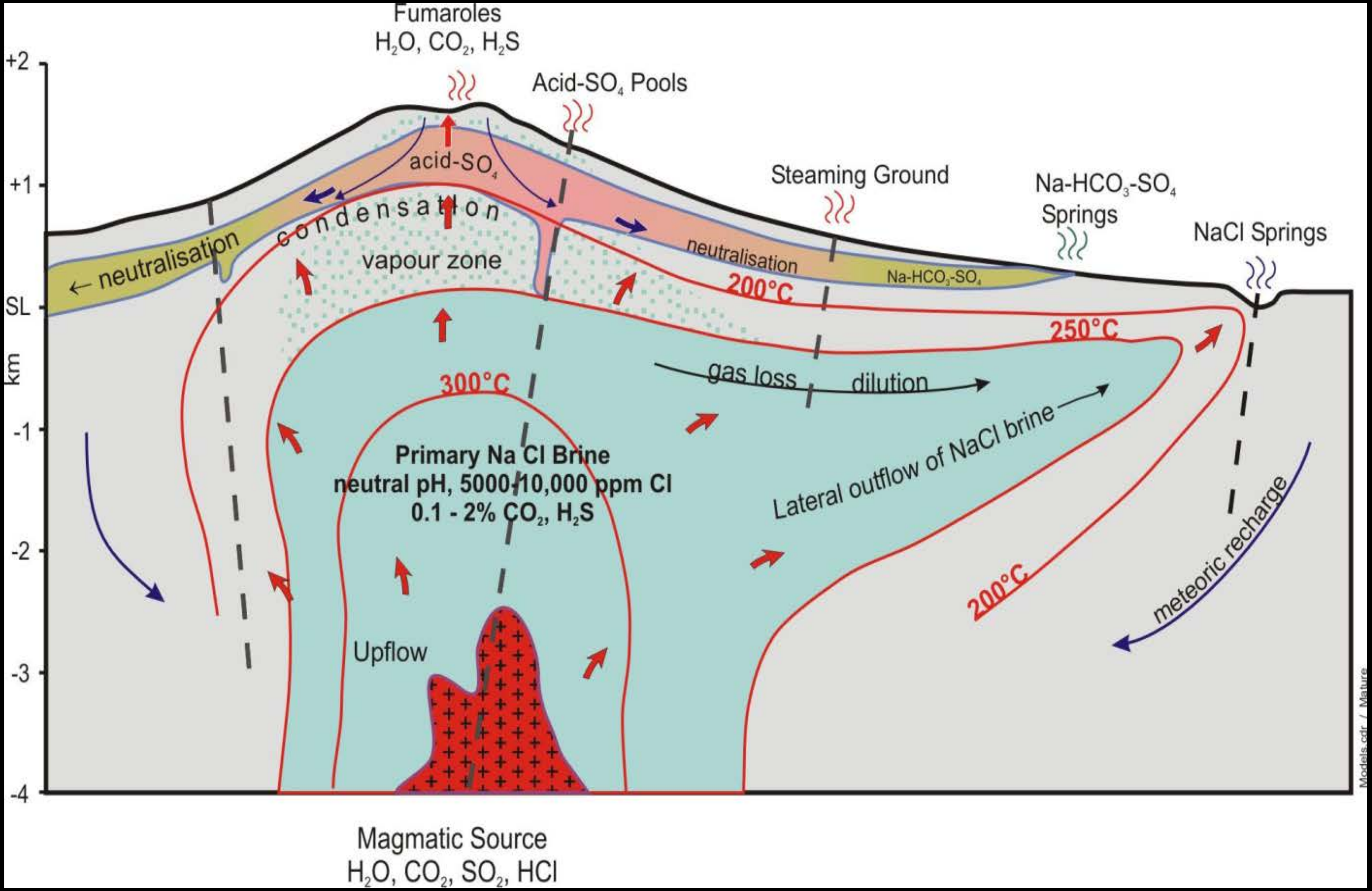
Ref: Success of Geothermal Wells: A global study

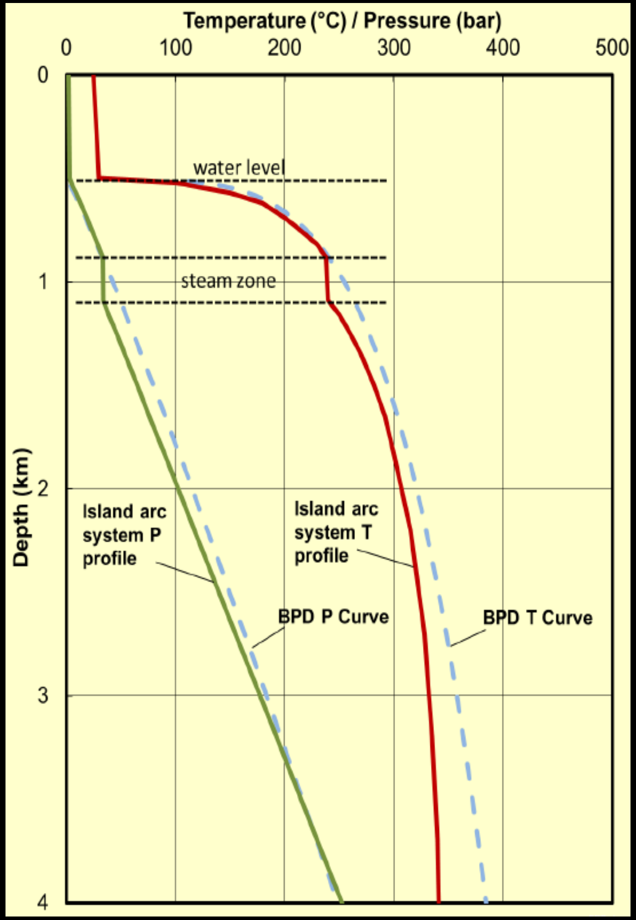
The submarine volcanoes is obvious in airborne magnetic survey.





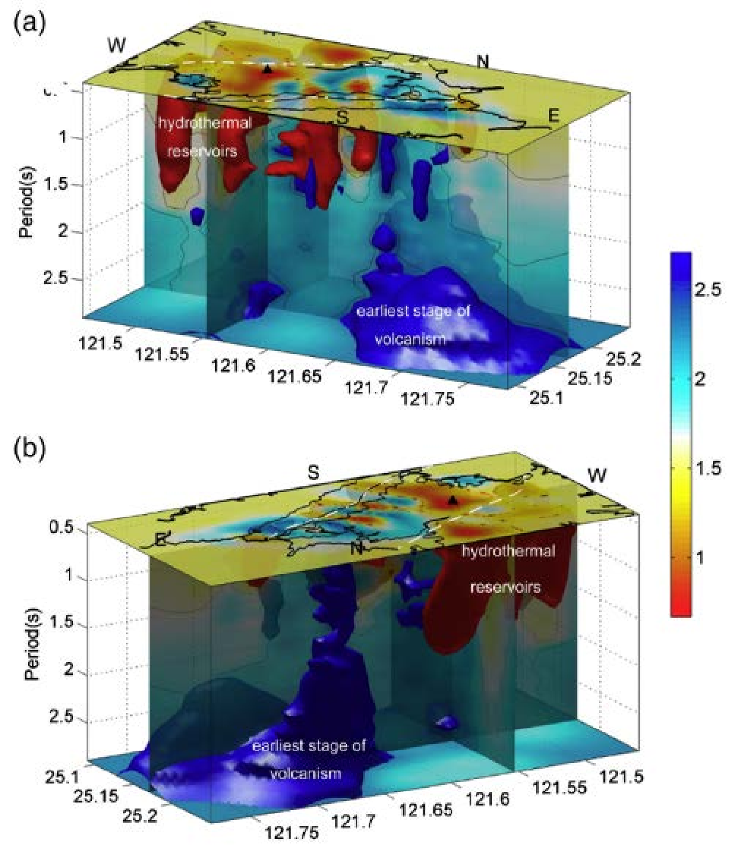
GEOTHERMAL CONCEPTUAL MODEL



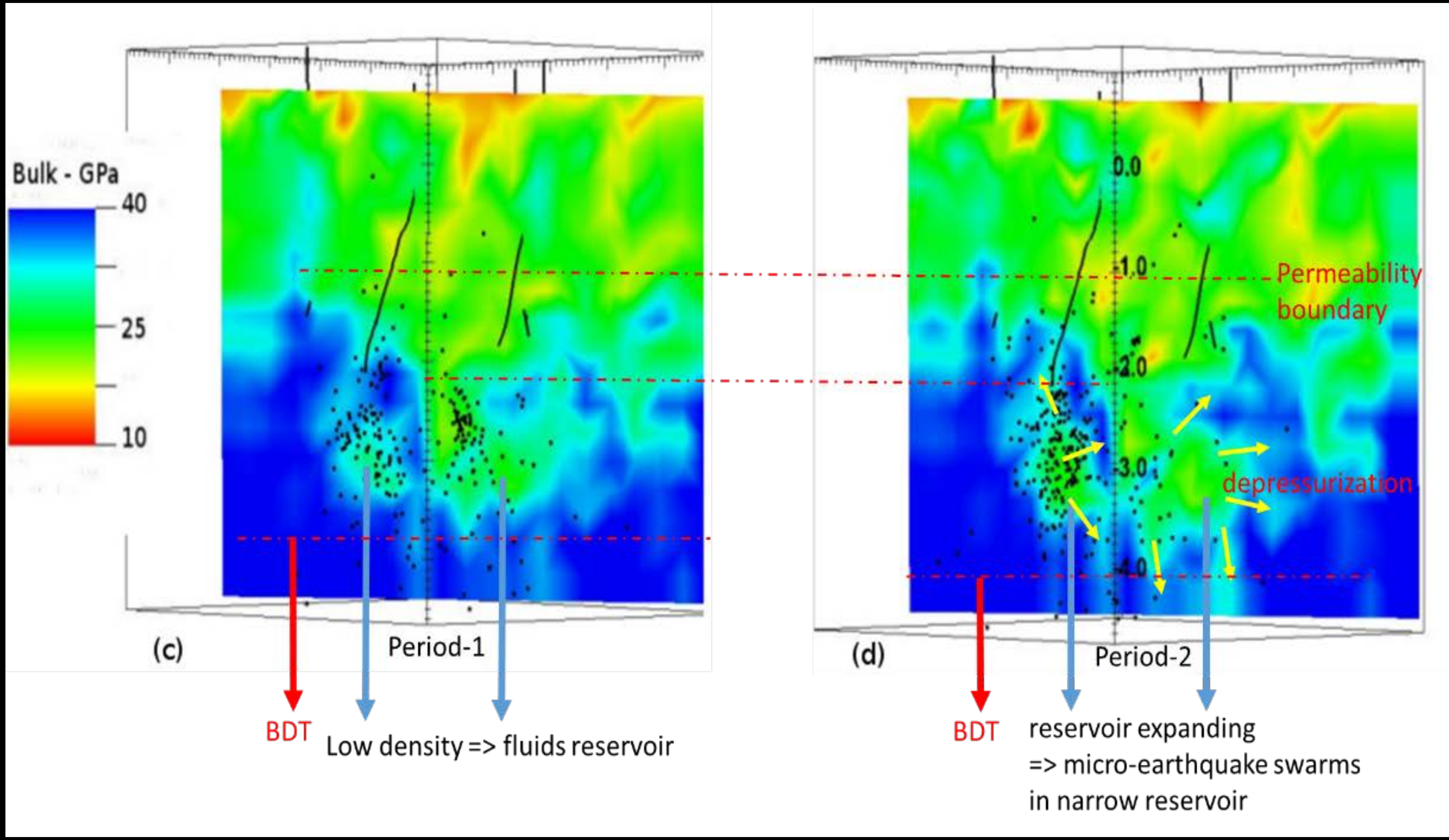


BPD：Boiling Point vs. Depth

HIGH RESOLUTION RESERVOIR EXPLORATION (WITH LBNL)



Y.-C. Huang et al. / Journal of Volcanology and Geothermal Research (2017)



利用高解析度微震探勘技術建構低風險地熱開發策略，技師期刊 2017，王守誠等

THE FIRST GEOTHERMAL POWER ON-GRID FROM 2001~2018

Why Geothermal Energy Promoted by UN

We have no much time left and we are beyond no return

WORKSHOP THEMES

UPSTREAM
Nature of the resource

Heat-sources and volcanos
Geothermal exploration
Geothermal modelling

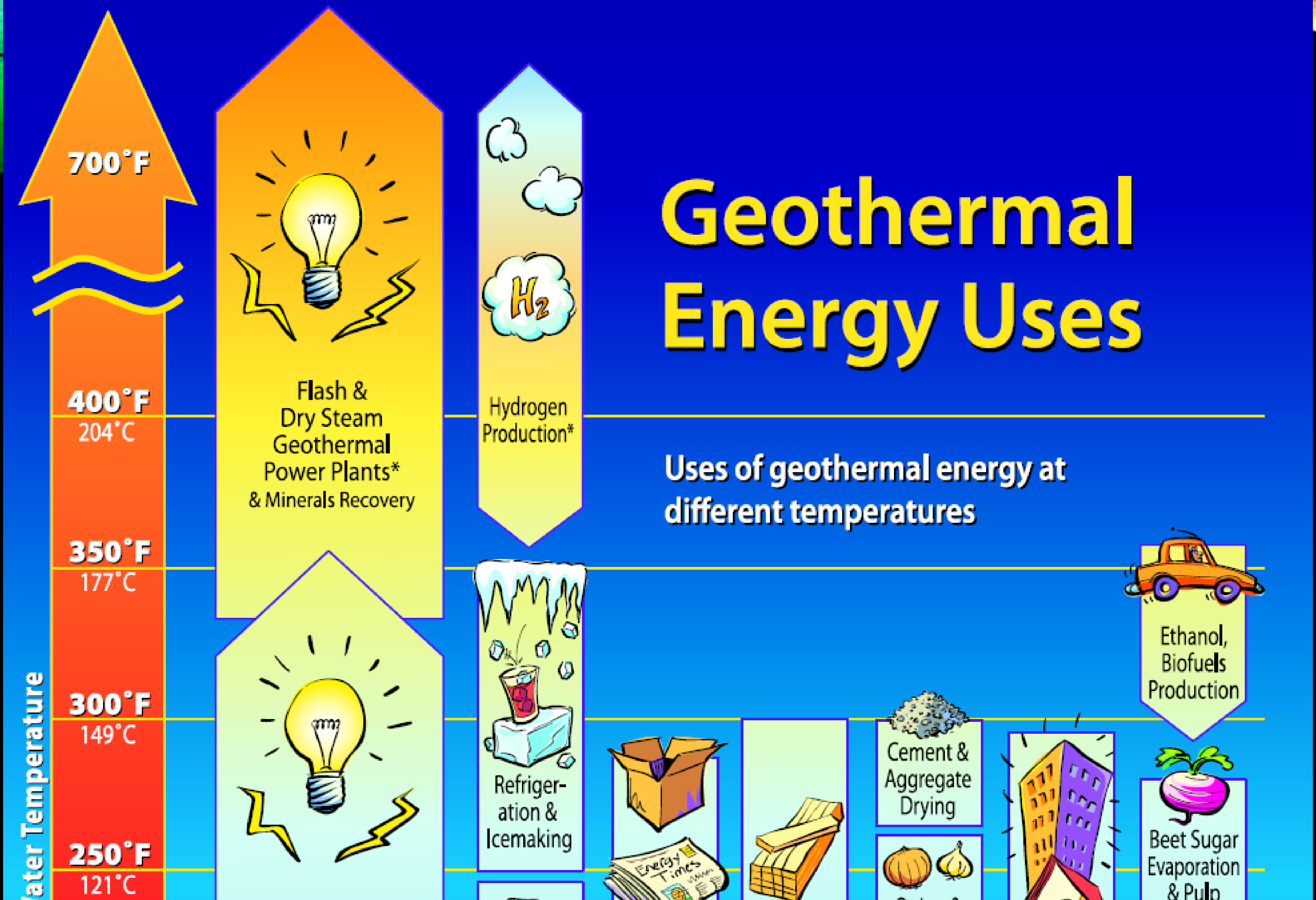
MIDSTREAM
Harnessing and production

Production technology
Power cycles
Well design

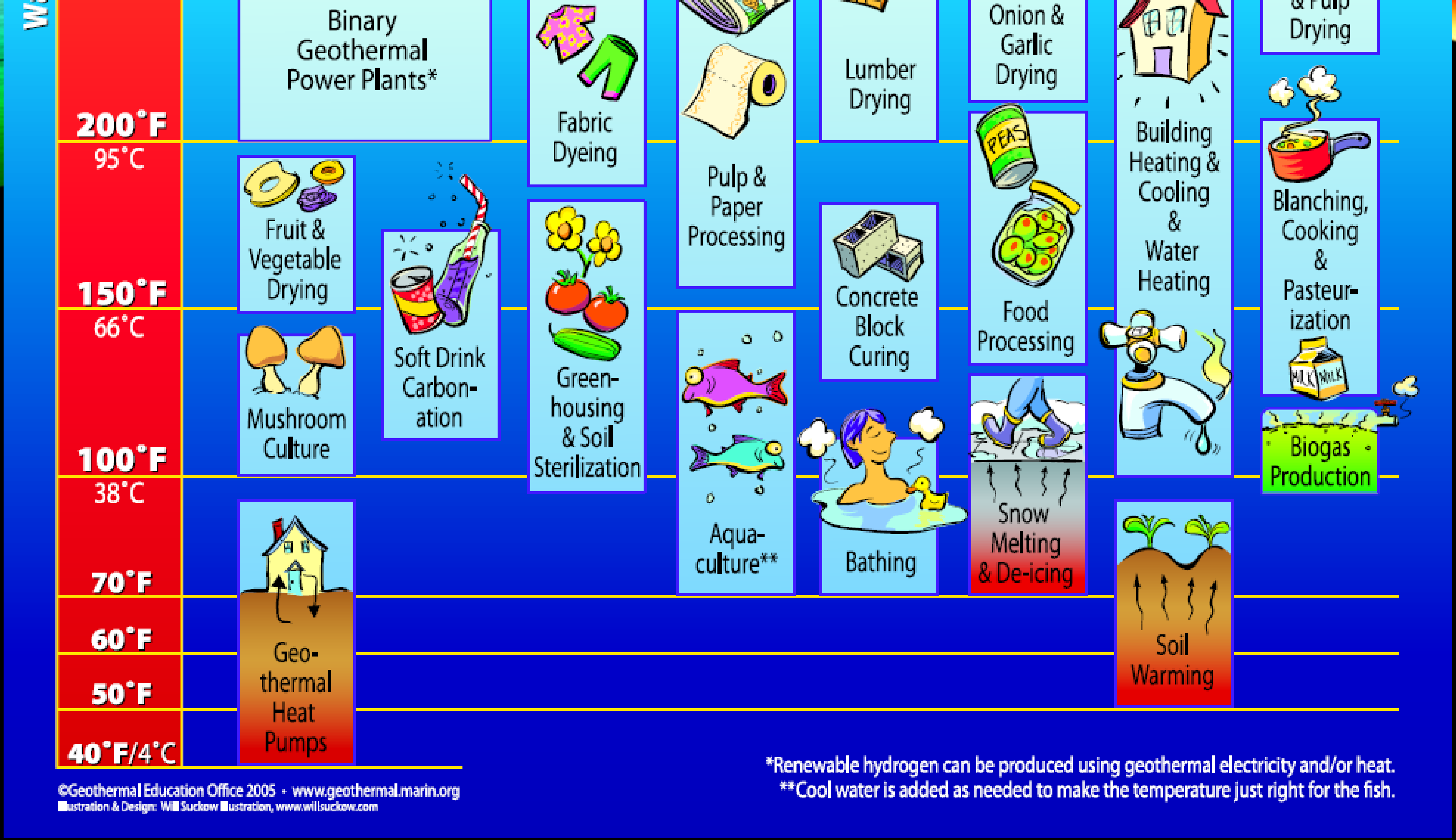
DOWNSTREAM
Diversified utilization

Cascaded use
Industrial applications
Waste to Value

CROSS- CUTTING
Sustainability – Social benefits – Innovation



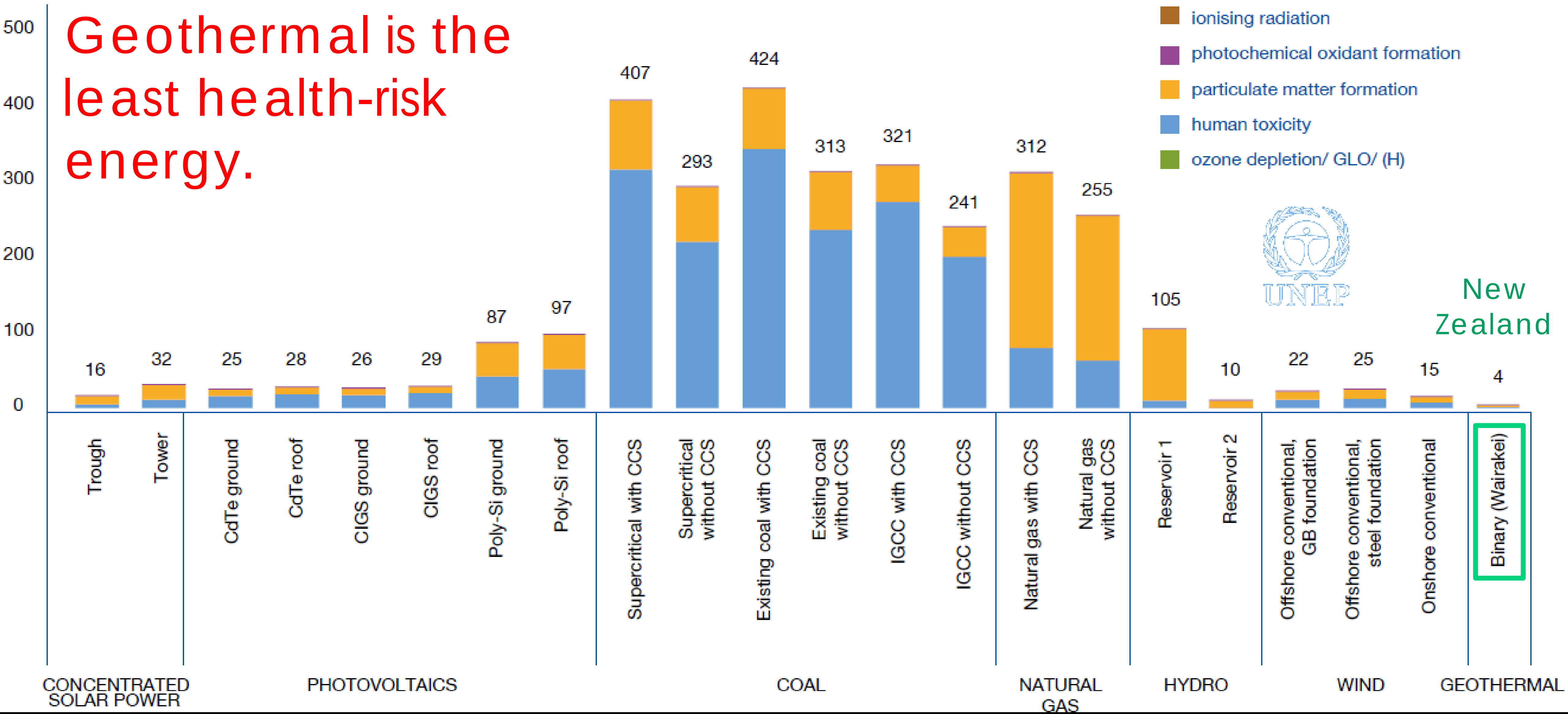
Geothermal Energy Uses
Uses of geothermal energy at different temperatures
700˚F
400˚F
204˚C
350˚F
177˚C
300˚F
149˚C
250˚F
121˚C
Water Temperature
Flash & Dry Steam Geothermal Power Plants* & Minerals Recovery
H2
Hydrogen Production*
Refriger-ation & Icemaking
Cement & Aggregate Drying
Ethanol, Biofuels Production
Beet Sugar Evaporation & Pulp



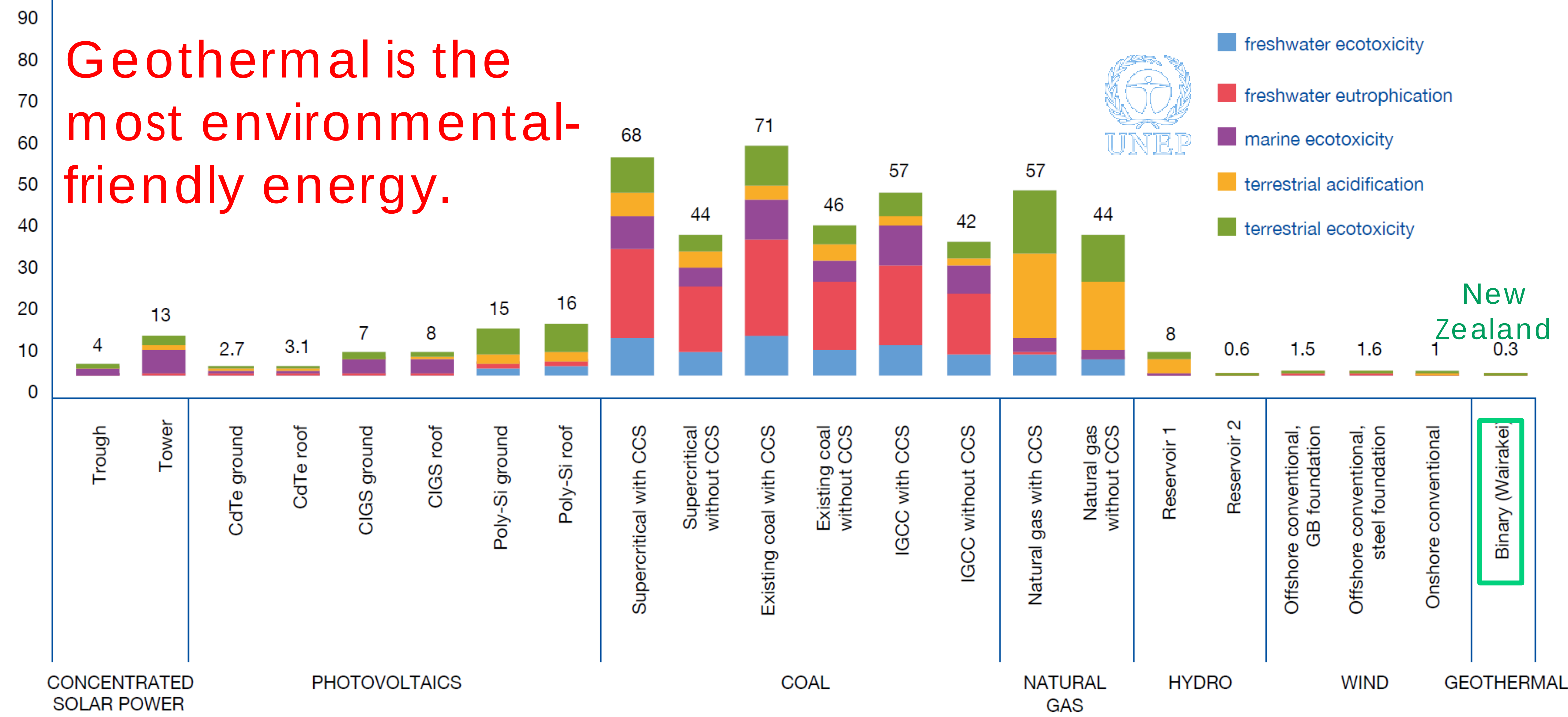
200˚F
95˚C
150˚F
66˚C
100˚F
38˚C
70˚F
60˚F
50˚F
40˚F/4˚C
Binary Geothermal Power Plants*
Fabric Dyeing
Pulp & Paper Processing
Lumber Drying
Onion & Garlic Drying
Building Heating & Cooling & Water Heating
Drying
Fruit & Vegetable Drying
Soft Drink Carbonation
Green-housing & Soil Sterilization
Concrete Block Curing
PEAS
Food Processing
Blanching, Cooking & Pasteurization
MILK
Mushroom Culture
Aquaculture**
Bathing
Snow Melting & De-icing
Biogas Production
Geothermal Heat Pumps
Soil Warming
*Renewable hydrogen can be produced using geothermal electricity and/or heat.
**Cool water is added as needed to make the temperature just right for the fish.
©Geothermal Education Office 2005 • www.geothermal.marin.org
Illustration & Design: Will Suckow Illustration, www.willsuckow.com

Clean steam plant, Kawerau geothermal plant, Taupo, New Zealand

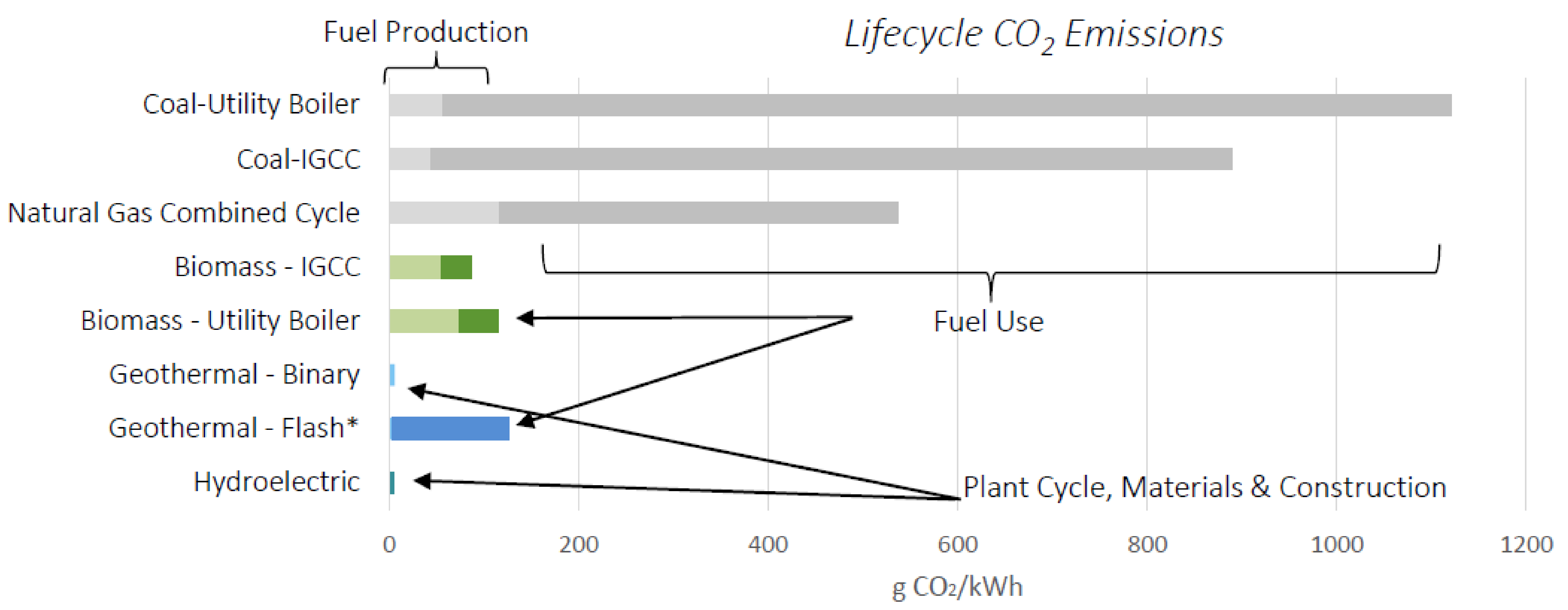
MERITS OF CONVENTIONAL GEOTHERMAL SYSTEM



MERITS OF CONVENTIONAL GEOTHERMAL SYSTEM



GREEN ENERGY CHOICES: The Benefits, Risks and Trade-Offs of Low-Carbon Technologies for Electricity Production, 2015 ((united nations environment programme)



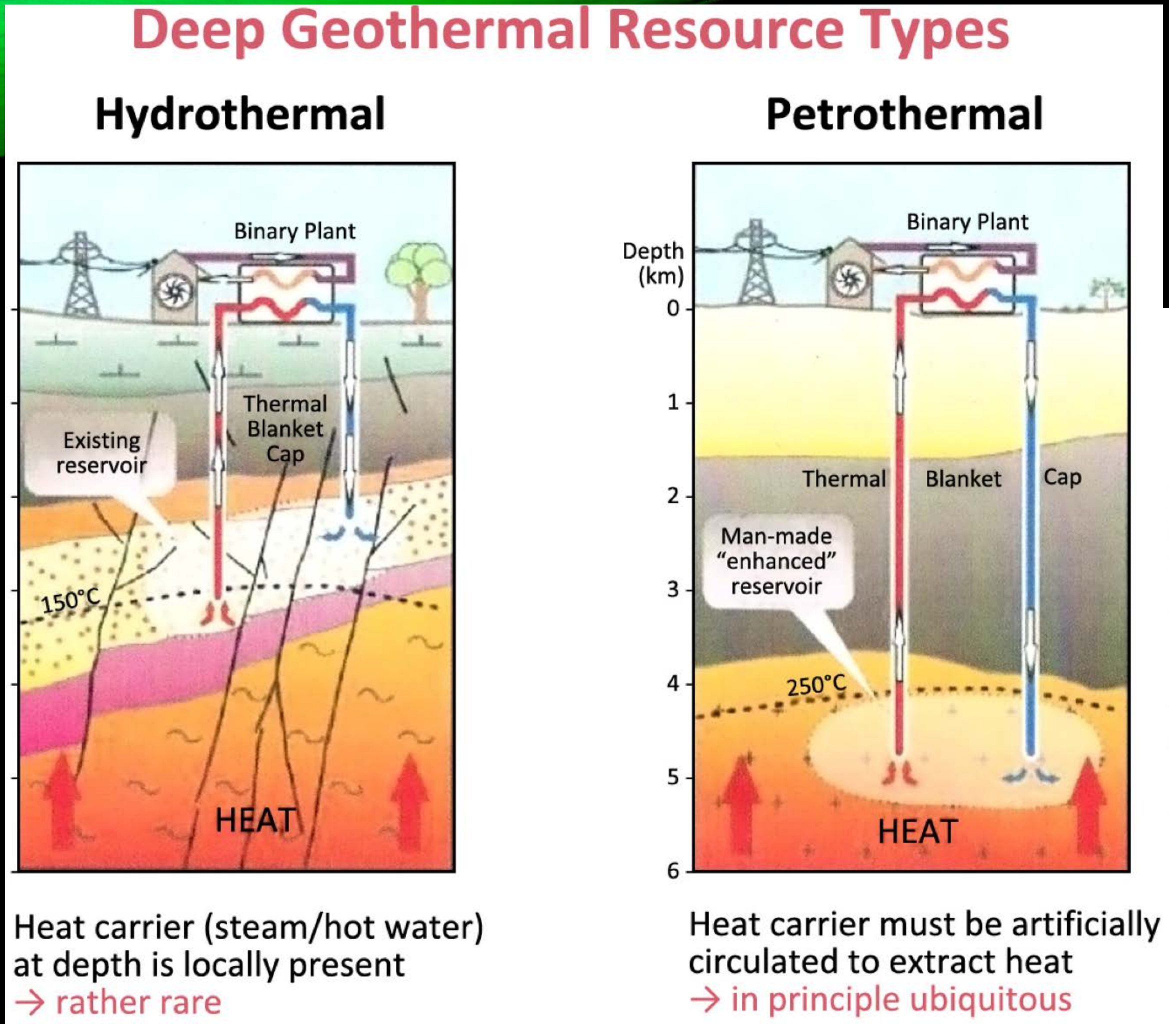
Baseload Renewables: The Important Facts, Baseload Renewable Energy Summit, 2016

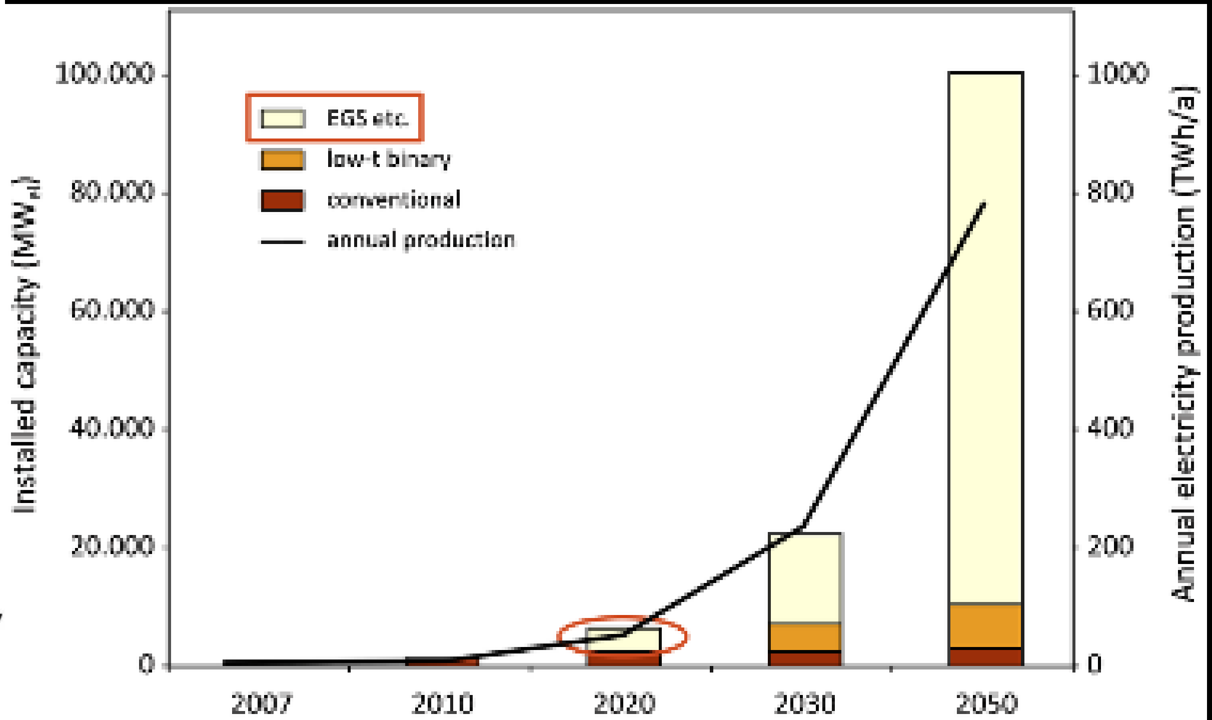
THE WELLHEAD GEOTHERMAL PLANT BUILT IN 16 WEEKS

AUTO DRILLING TECHNOLOGY

How Geothermal Energy Promoted by UN

We have no much time left and we are beyond no return

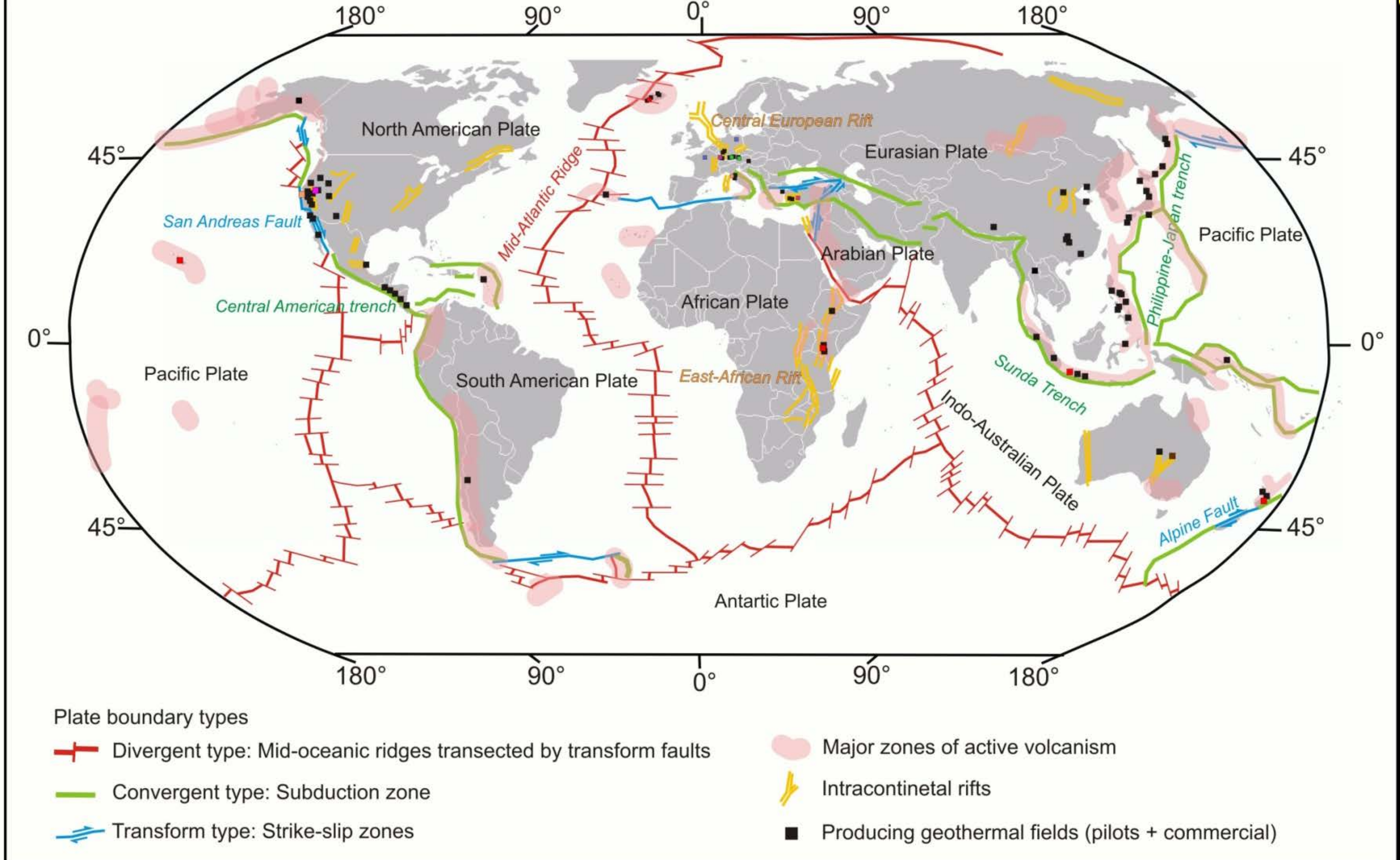




Conventional Geothermal System-CGS

Enhanced Geothermal System-EGS =Hot Dry Rock

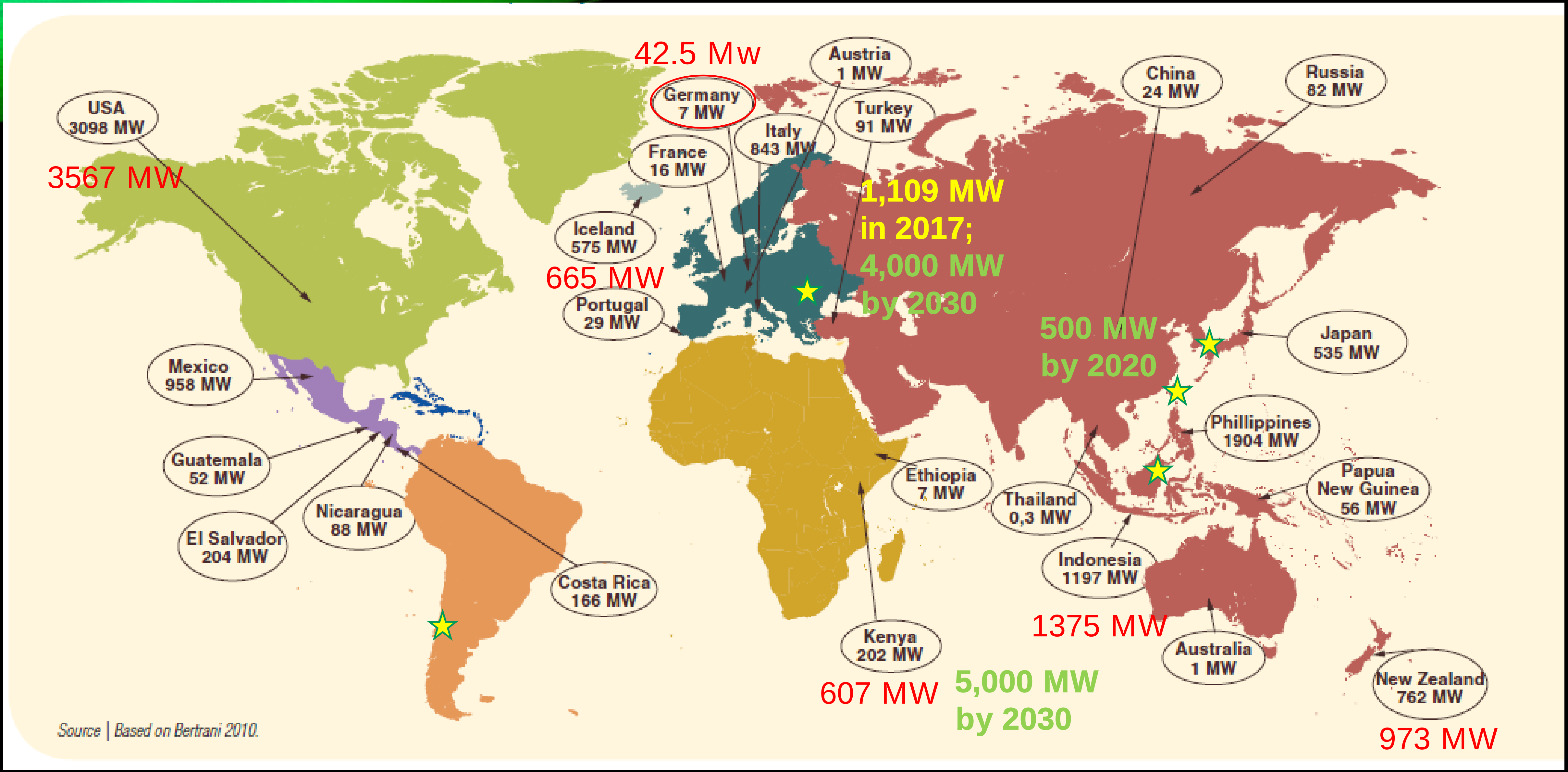
Ladislaus Rybach, 2014



Geothermal plays with geothermal production projects

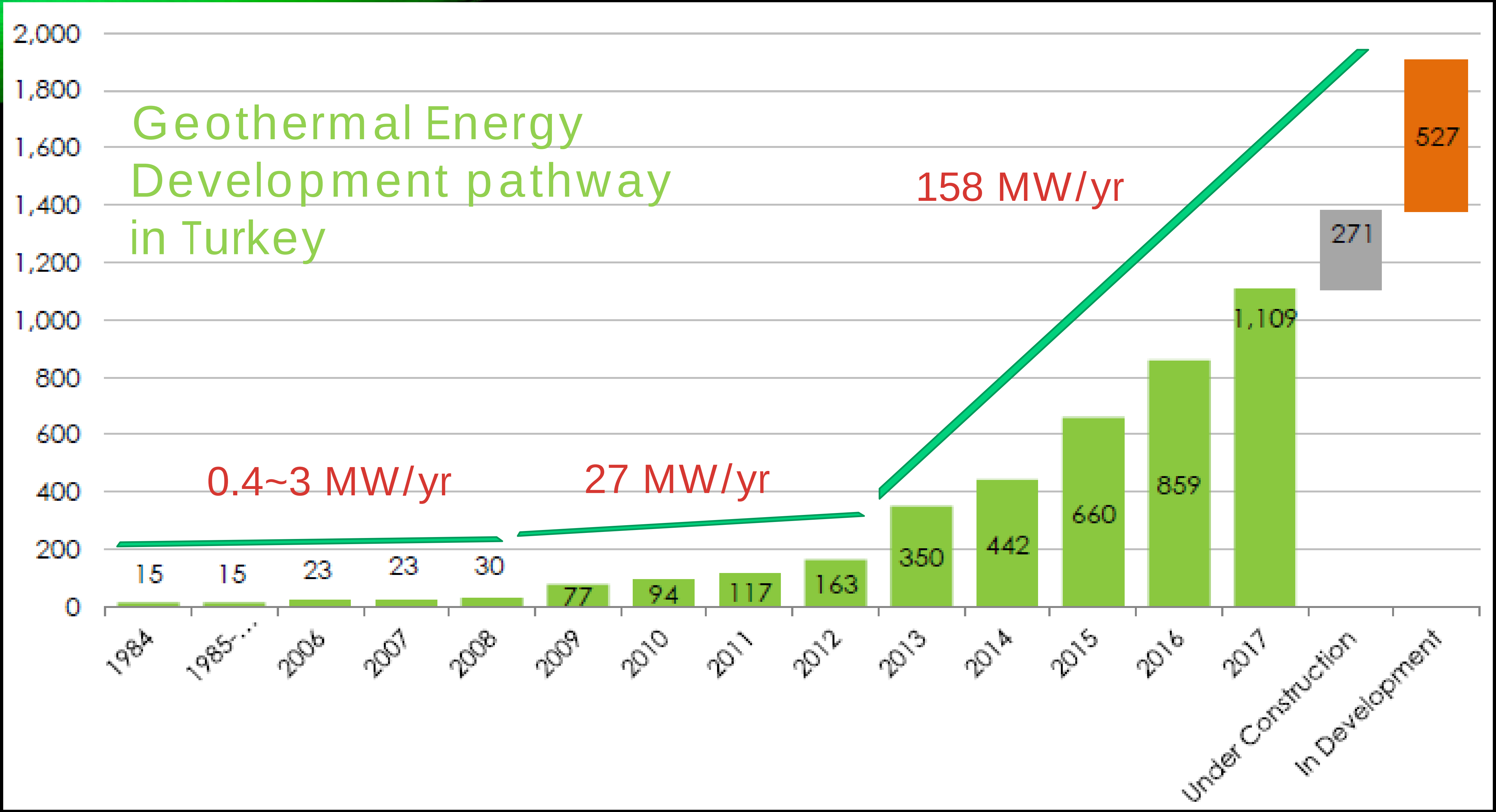
CV1a - Magmatic: active or recent magmatism: Taupo (New Zealand), Kamojang (Indonesia), Reykjanes (Iceland), Puna (Hawai/USA)
CV1b - Magmatic: inactive/extinct magmatism: Larderello (Italy), The Geysers (USA)
CV2 - Non-magmatic: Extensional domain type: Bradys (Nevada/USA), Kizildere (Turkey), Soulz-sous-Forets (France)
CD1 - Intracratonic Basin Type: Neustadt-Glewe [heat] (Germany), Paris Basin [heat] (France)
CD2 - Orogenic Belt Type: Unterhaching (Germany), Altheim (Austria)
CD3 - Basement (hot dry rock) Type: Habanero (Australia)

Inga S. Moeck, 2015



~~24~~ 28 countries use geothermal power in 2020

Data from 「2016 Annual U.S. & Global Geothermal Power Production Report」



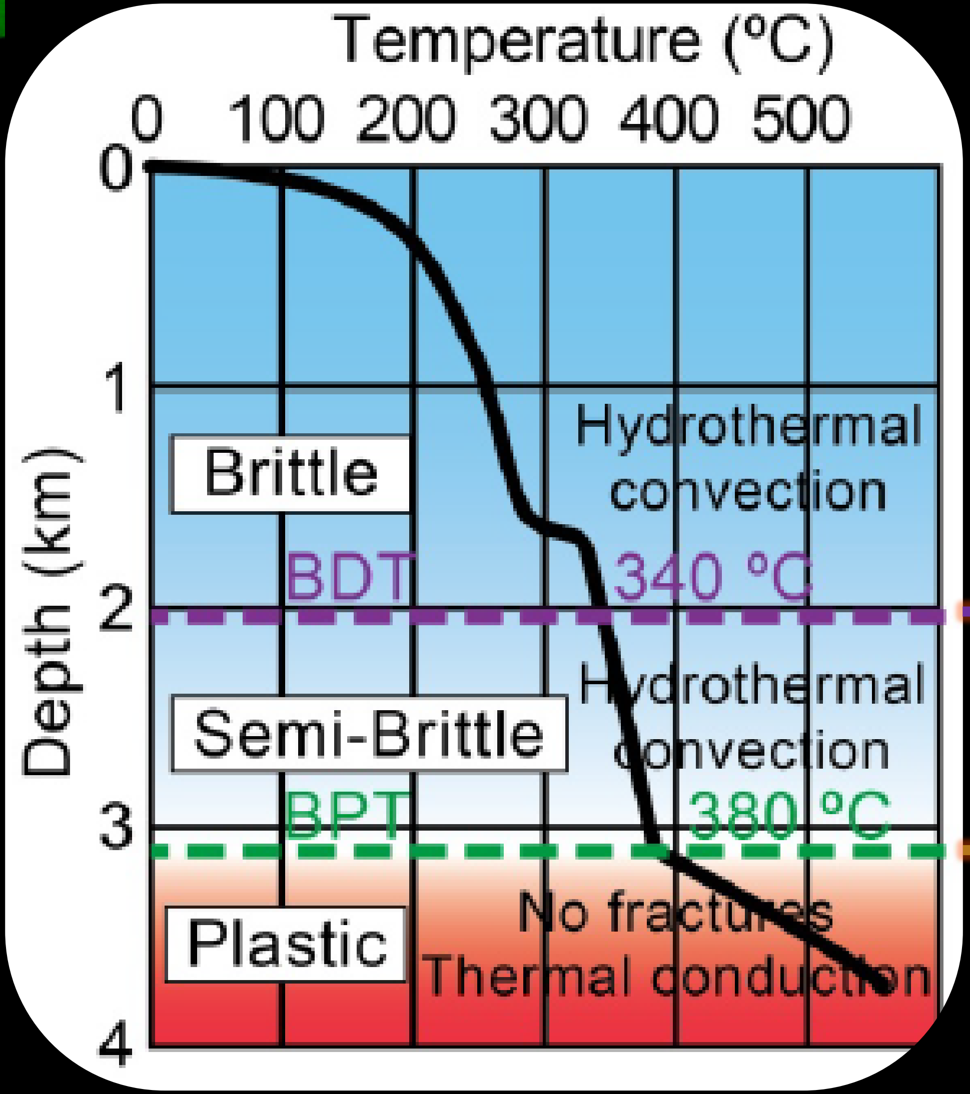
Geothermal Energy
Development pathway
in Turkey
0.4~3 MW/yr
27 MW/yr
158 MW/yr
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
15
15
23
23
30
77
94
117
163
350
442
660
859
1,109
271
527
1984
1985-…
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Under Construction
In Development


blue lagoon in Kenya
Photo by: Amy Yee

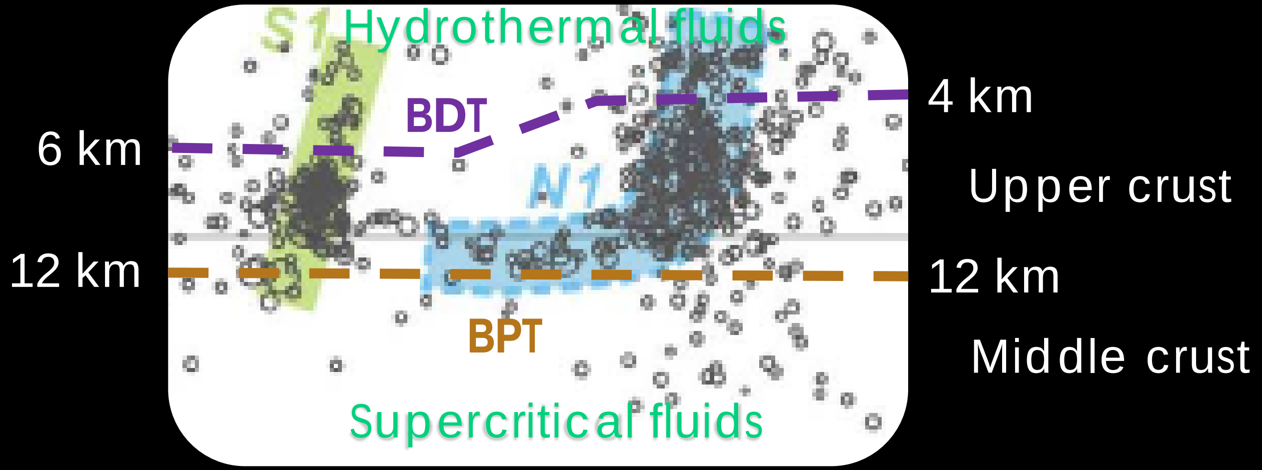
Conclusions & What we have done

We have no much time left and we are beyond no return

Suzuki et al., 2014



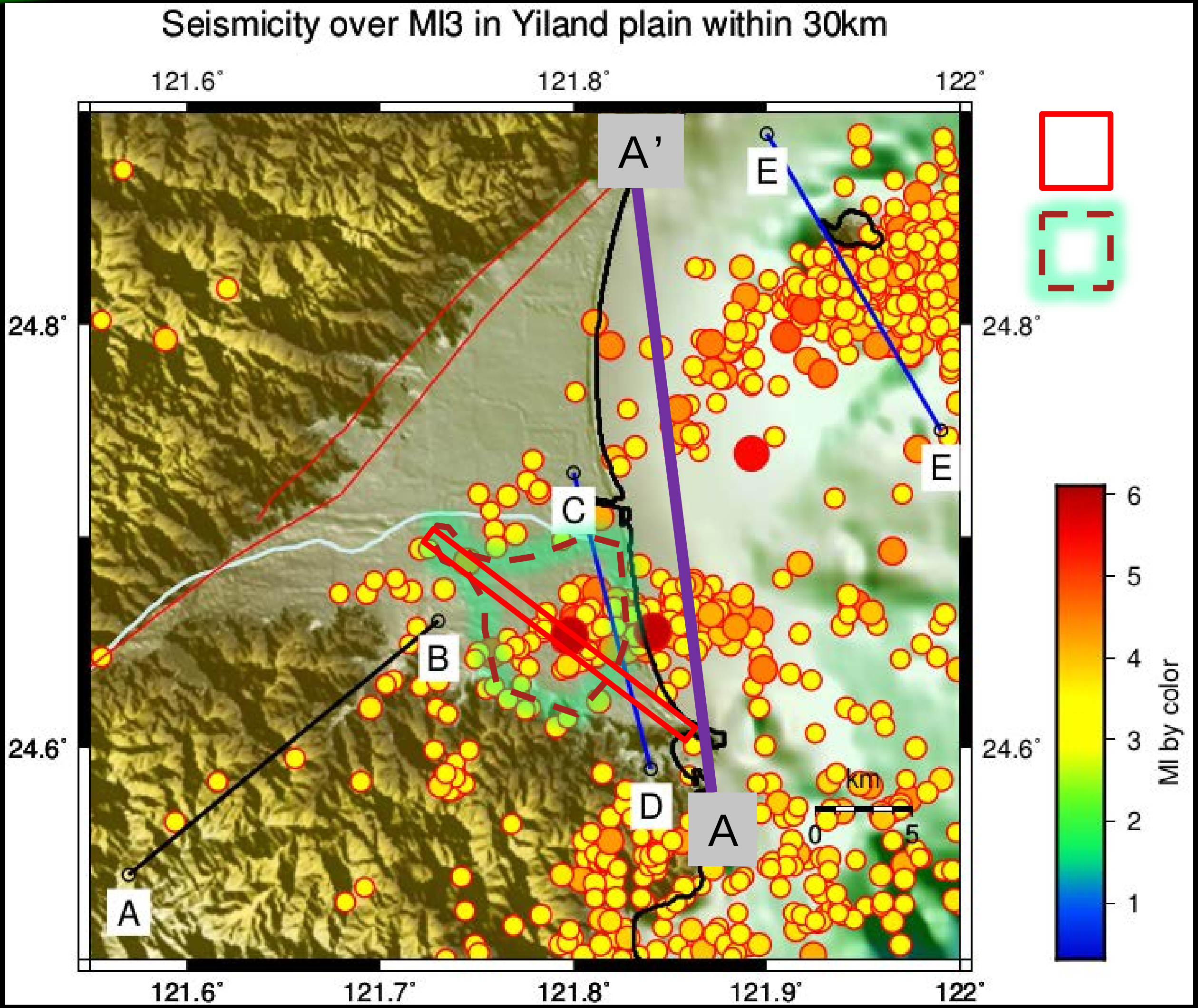
Relocated seismic activities M_L >4.0
Huang H. H. et al., 2012

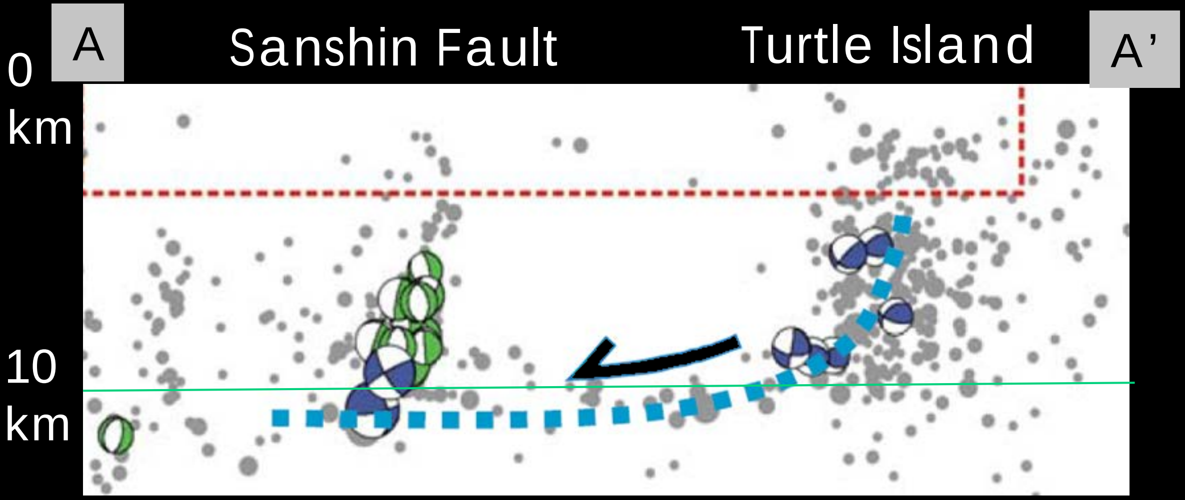


the maximum strength zone, a nest of earthquakes and fractures.

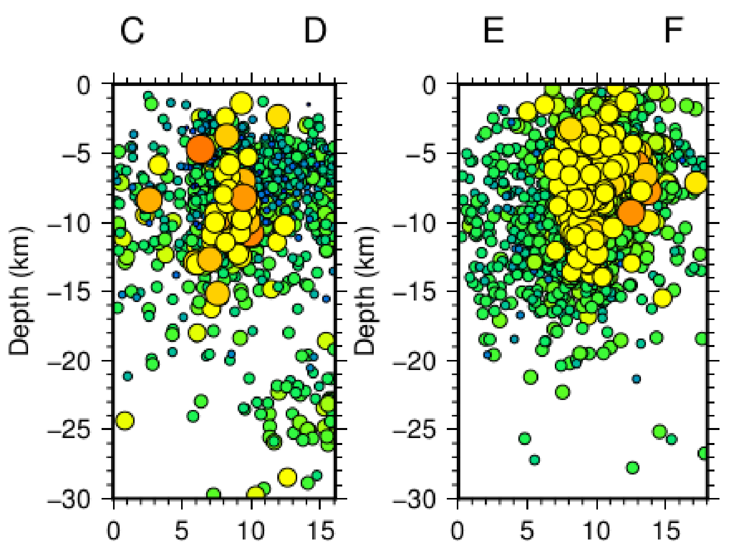
a bottom surface of seismicity, fracturing and hydrothermal convection

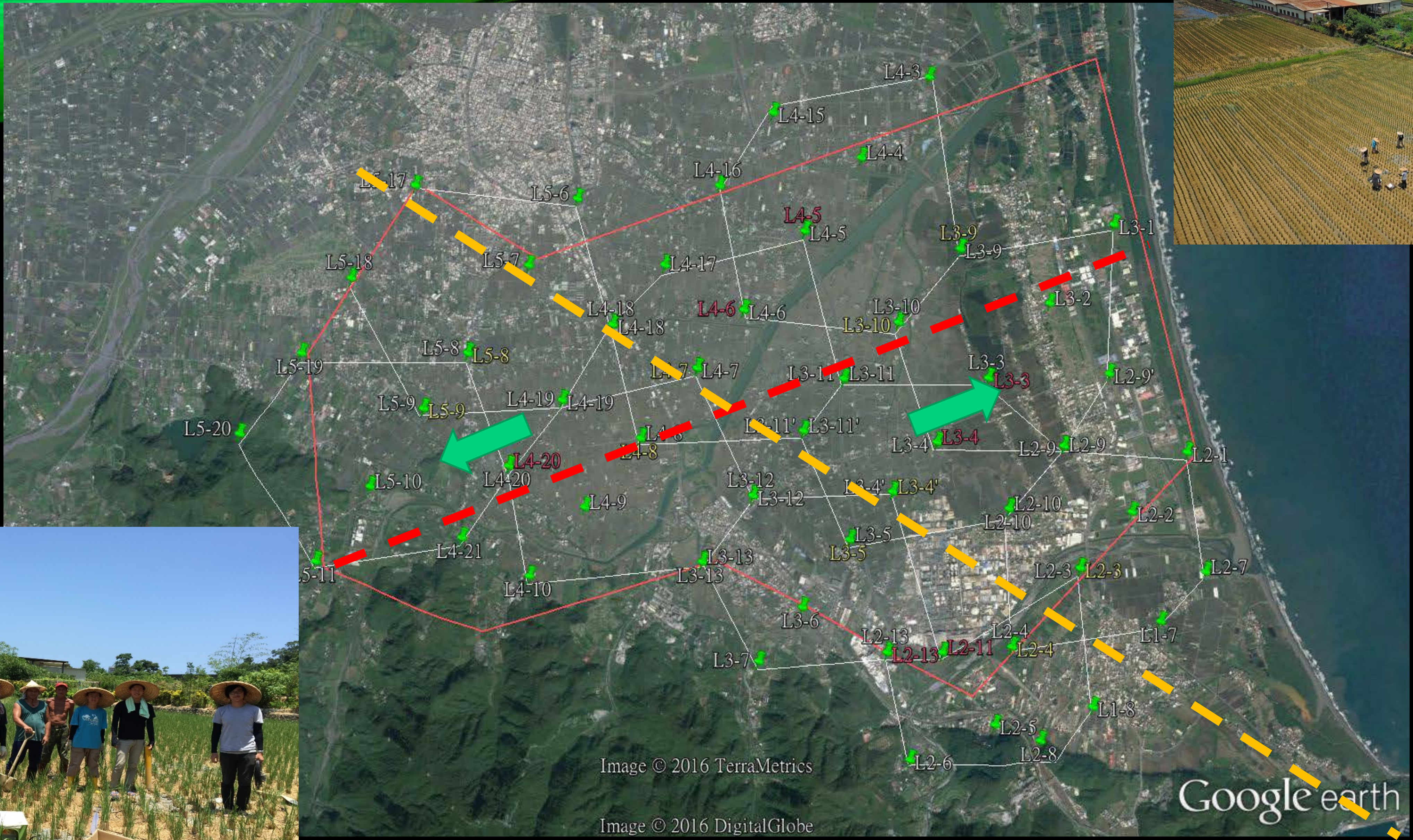
SELF-ORGANIZATION OF EARTHQUAKE SWARMS IN GEOTHERMAL FIELDS





Huang H. H., 2007




L4-3
L4-15
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L3-9
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L5-7
L4-17
L3-10
L3-2
L4-18
L4-6
L5-8
L5-19
L4-7
L3-11
L3-3
L2-9'
L5-9
L4-19
L3-11'
L5-20
L3-4
L2-9
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L4-20
L5-10
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L3-12
L3-4'
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L2-10
L2-2
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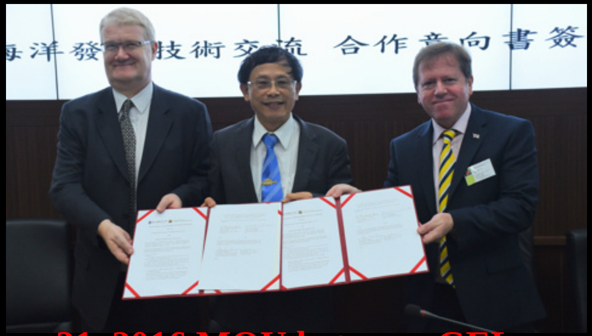
L2-4
L3-7
L1-8
L2-5
L2-8
L2-6
Image © 2016 TerraMetrics
Image © 2016 DigitalGlobe
Google earth

GEOTHERMAL PROMOTION TEAM

1. National Energy Project 2nd stage
2. NTOU(National Taiwan Ocean Univ.) has organized with several local and foreign companies for promoting geothermal energy.
3. We wish to cooperate in essential issues with IGA and IEA-GEA, expanding to environmental impact & monitoring and legal experience.

Sep. 4, 2015 MOU between LCY and NTOU



Jan. 21, 2016 MOU between GEL and NTOU

STRATEGIES FOR TOUGH GOAL: 150 MW IN 2020

Short-term strategies

- Setting up geothermal well database from CPC, ITRI and WRA (of MOEA). => MOEA developing
- Transforming Petroleum fund of MOEABOE to national risk mitigation fund => MOEA done by 「Geothermal power system demonstration incentives」
- International cooperation in mature geothermal technologies. => private company developing
- Developing air drilling technology to further geothermal drilling case. => private company developing
- Establish Expanded Business Model Working Group (EBMWG) for geothermal development
  => Preparatory Office of Taiwan Geothermal Energy Alliance

Long-term strategies

- Cultivating technical manpower for geothermal engineering via international cooperation.
- Building up Geothermal Energy Law and a national geothermal committee to reduce risks and cost.

1. Subvolcanic geothermal exploration

~~2.NTOU campus geothermal project with hydrogen hybrid pilot~~

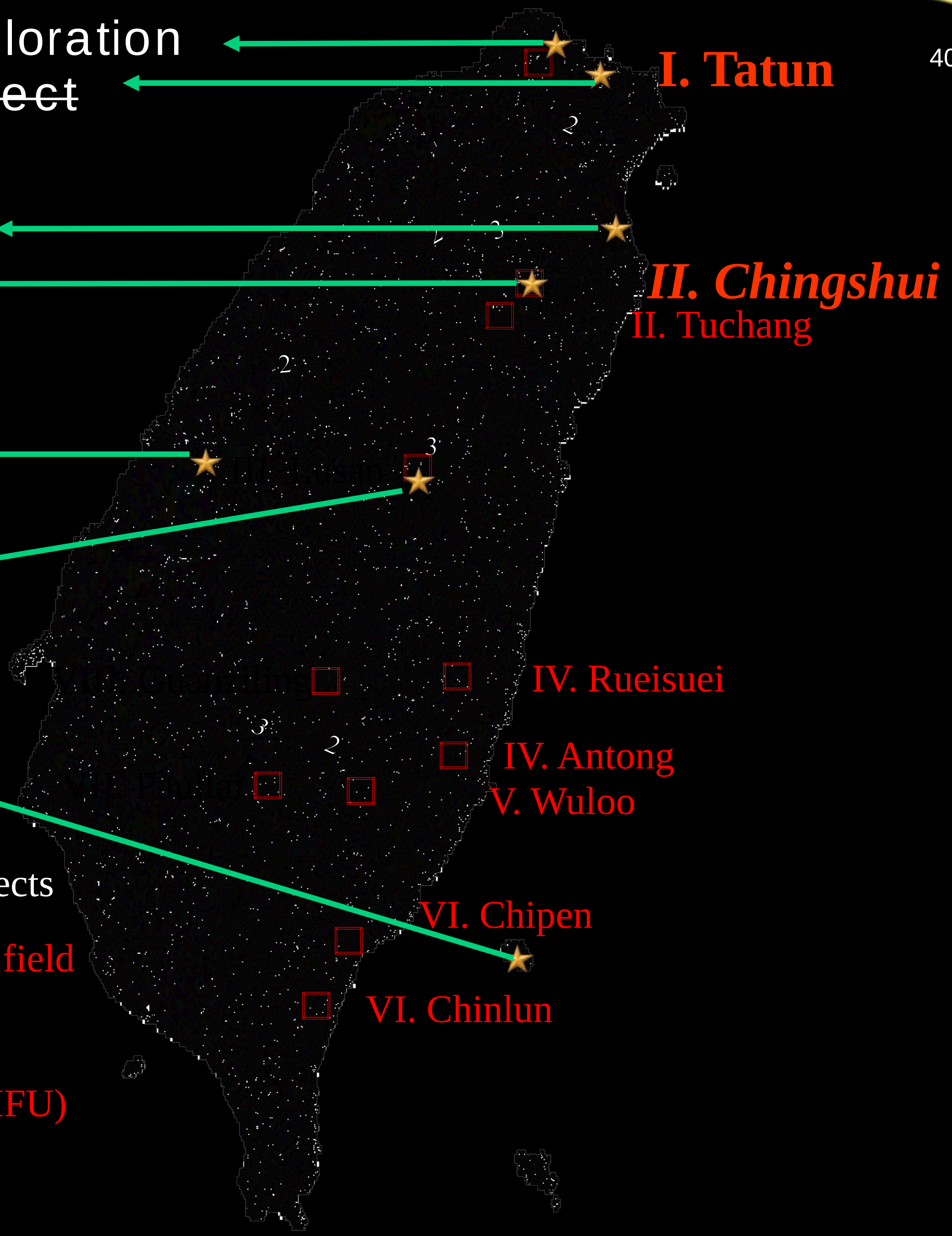
3.EIA approved, 101 Mwe CEEG project

4.ROT & BOT geothermal project

~~5.Biomass hybrid geothermal project~~

6.Sediq Geothermal Village

~~7.Volcanic island geothermal project~~



★ NTOU promoting projects

□ Potential geothermal field

● Hot spring spot

Heat flow contour (HFU)

Statistics:

1. Size of country: 783,562 km^2.
2. Population: 78,741,053 (2015).
3. Years of producing electricity from geothermal: 32 years, from 1984.
4. Installed capacity of geothermal (MWe): 820 MWe (2017).
5. Installed capacity of other sources (MWe): 77,614 MWe (2015).
6. Electricity production from geothermal (GWh): 3,424 GWh (2015).
7. Electricity production from other sources (GWh): 254,935 GWh.
8. Proportional production by source:

- Coal – 29.09%
- Natural Gas – 37.90%
- Liquid Fuels – 0.85%
- Hydro – 25.65%
- Wind – 4.45%
- Waste Heat – 0.16%
- Biomass – 0.52%
- Solar – 0.07%
- Geothermal – 1.31%

GEOTHERMAL-TRANSPARENCY-GUIDE_ABB

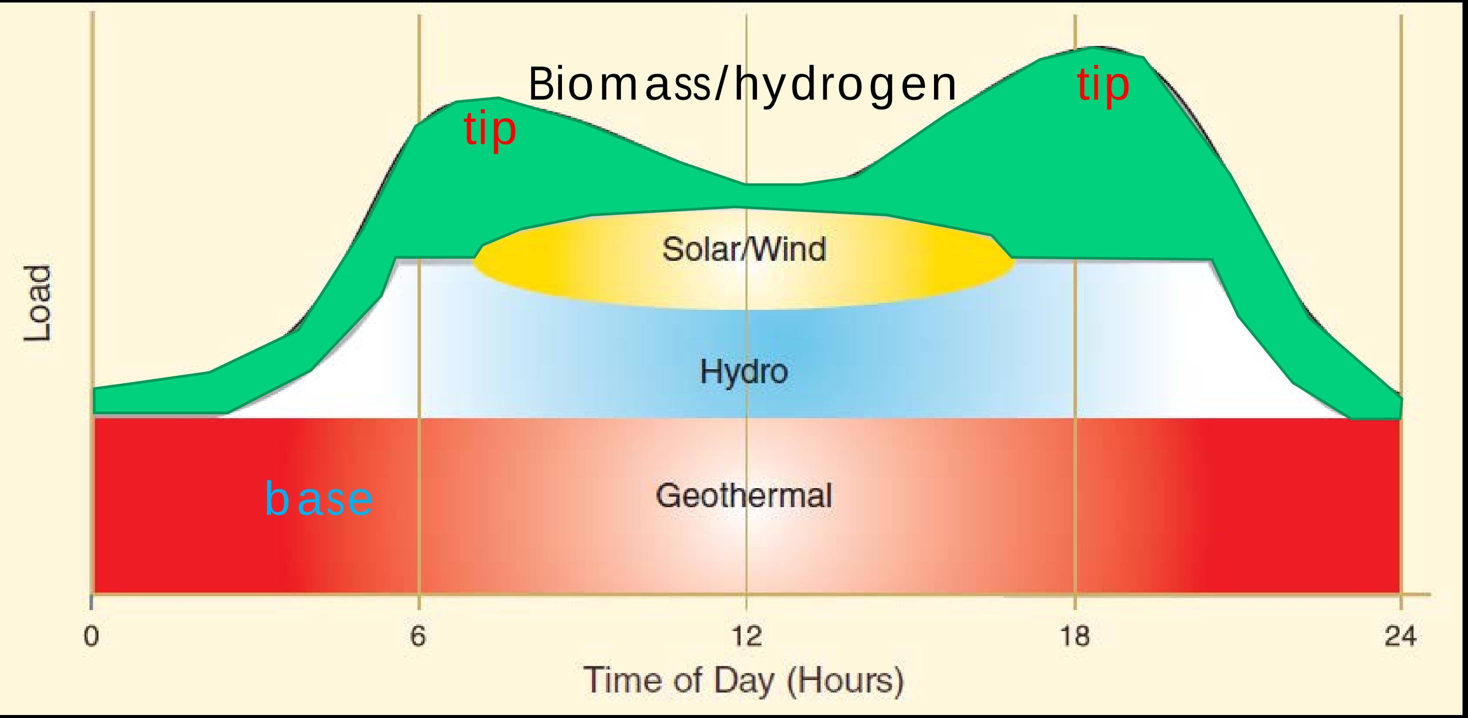
GEOTHERMAL ACT

Boosting geothermal energy more than 1,000 MW from 2008~2018

Cheap geothermal power as NTD 3 /kWh

THE IDEAL ENERGY STRUCTURE

1. Geothermal can play the distributed base-loading power in region.
2. For better performance, replacing tip-loading fossil fuels by storable clean energy is essential, like hybrid geothermal plant with biomass, hydrogen fuel cell.



CIVIL GEOTHERMAL PLANT

1. Place: Letzer industrial area in Yiland plain
2. Heat source：hydrothermal reservoir in Sanxin fracture zone
3. Estimated depth：2000~5000 meters(200~300°C)
4. Operation：BOT(Build-operate-transfer) or PPP(Public-Private-Partnership)
5. Civil geothermal plant can be part of “circular economy” in local, especially in low-carbon tech.
6. Benefit corporation(B corp.) certificate, ISO14001(like Valle Secolo geothermal plant) for a greener and more public power supplier.

Thanks for your attention.

We do not have much time left.

Costs of Energy, Including Transmission (¢ / kWh)

ENERGY TECHNOLOGY	2010-2013	2020-2030
Wind onshore	4-10.5	≤4
Wind offshore	11.3-16.5	7-10.9
Wave	>11	4-11
Geothermal	9.9-15.2	5.5-8.8
Hydroelectric	4-6	4
CSP(concentrating)	14.1-22.6	7-8
Solar PV (utility scale)	11.1-15.9	5.5
Tidal	>>11	5-7
Conventional (+Externalities)	9.2 (+5.3)=14.5	14-19 (+5.7)=20-25

Jacobson et al. (2013)

		230~300C: 25 MW/well	190~230C 3-12 MW/well	150~190C 3-5 MW/well
		Unit Cost (US ¢/kWh) High Quality Resource	Unit Cost (US ¢/kWh) Medium Quality Resource	Unit Cost (US ¢/kWh) Low Quality Resource
300 houses	Small plants (<5 MW)	5.0-7.0	5.5-8.5	6.0-10.5 NTD 3.15元/kWh
	Medium Plants (5-30 MW)	4.0-6.0	4.5-7	Normally not suitable
Over 9,000 houses	Large Plants (>30 MW)	2.5-5.0 NTD 0.75元/kWh	4.0-6.0	Normally not suitable

地熱	無區分	≥1	固定 20 年躉購費率		5.1956
			階梯式躉購費率	前 10 年	6.1710（5.6447）註 3
				後 10 年	3.5685（4.4465）註 3