

**Nordic Conference on Production and Use of  
Renewable Energy, July 9 -11, 2008, Vaasa, Finland**

# **Renewable Energy Resources in Iceland – Environmental Policy and Economic Value**

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# The value of the resources

- 3 condition for a rising resource value
  - Relatively plentiful Renewable energy resource availability
  - Market development with price increases due to scarcity or environmental restrictions
  - Market access and the possibility of transmitting to a wider market
- Iceland exemplifies these conditions

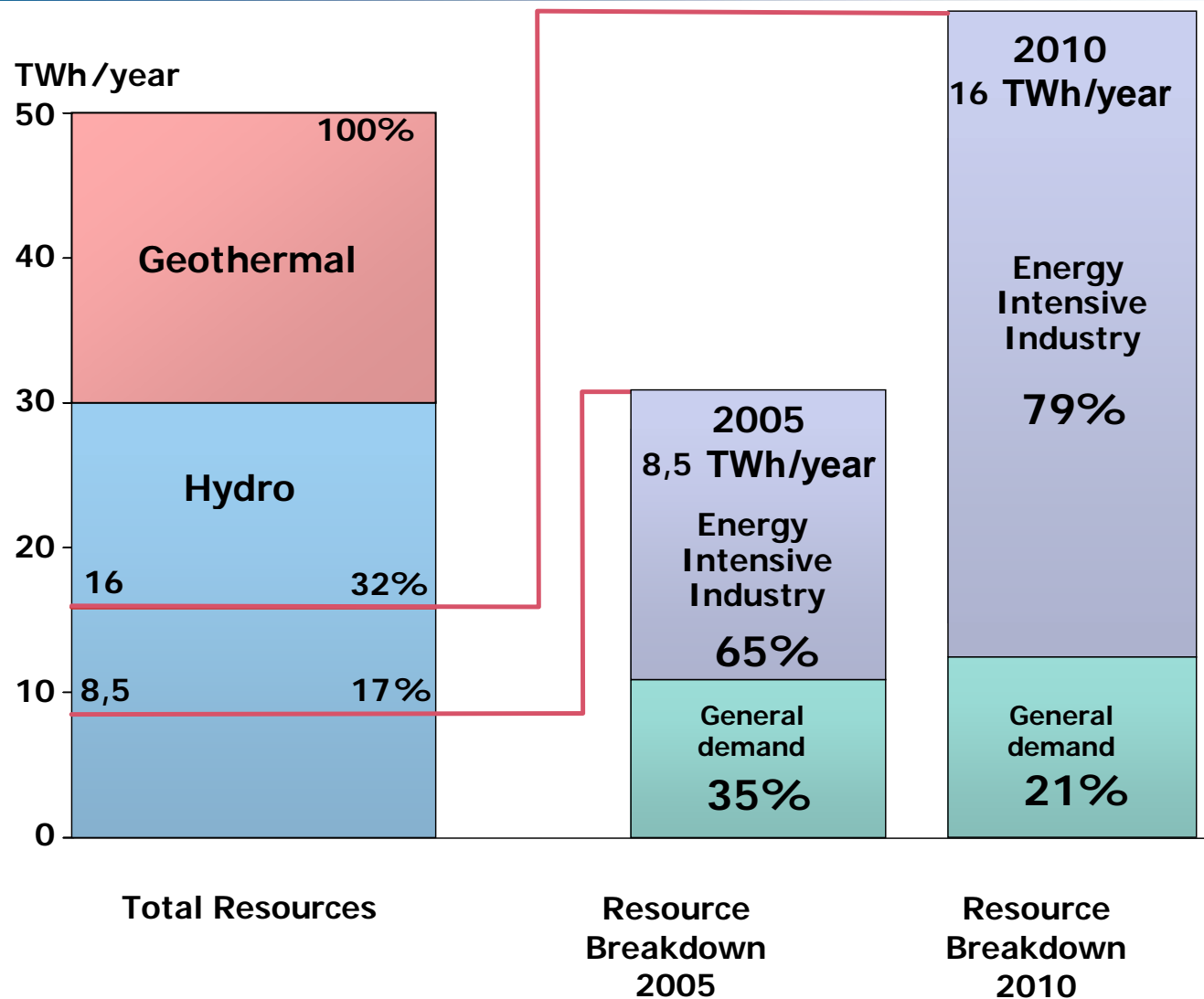


# **Icelandic renewable energy characteristics**

- **Iceland has a relative abundance of renewable, emission free hydro- and geothermal resources,**
- **Highest per capita utilization of these energy resources in the world and**
- **The fastest growing power and energy sector in the world**



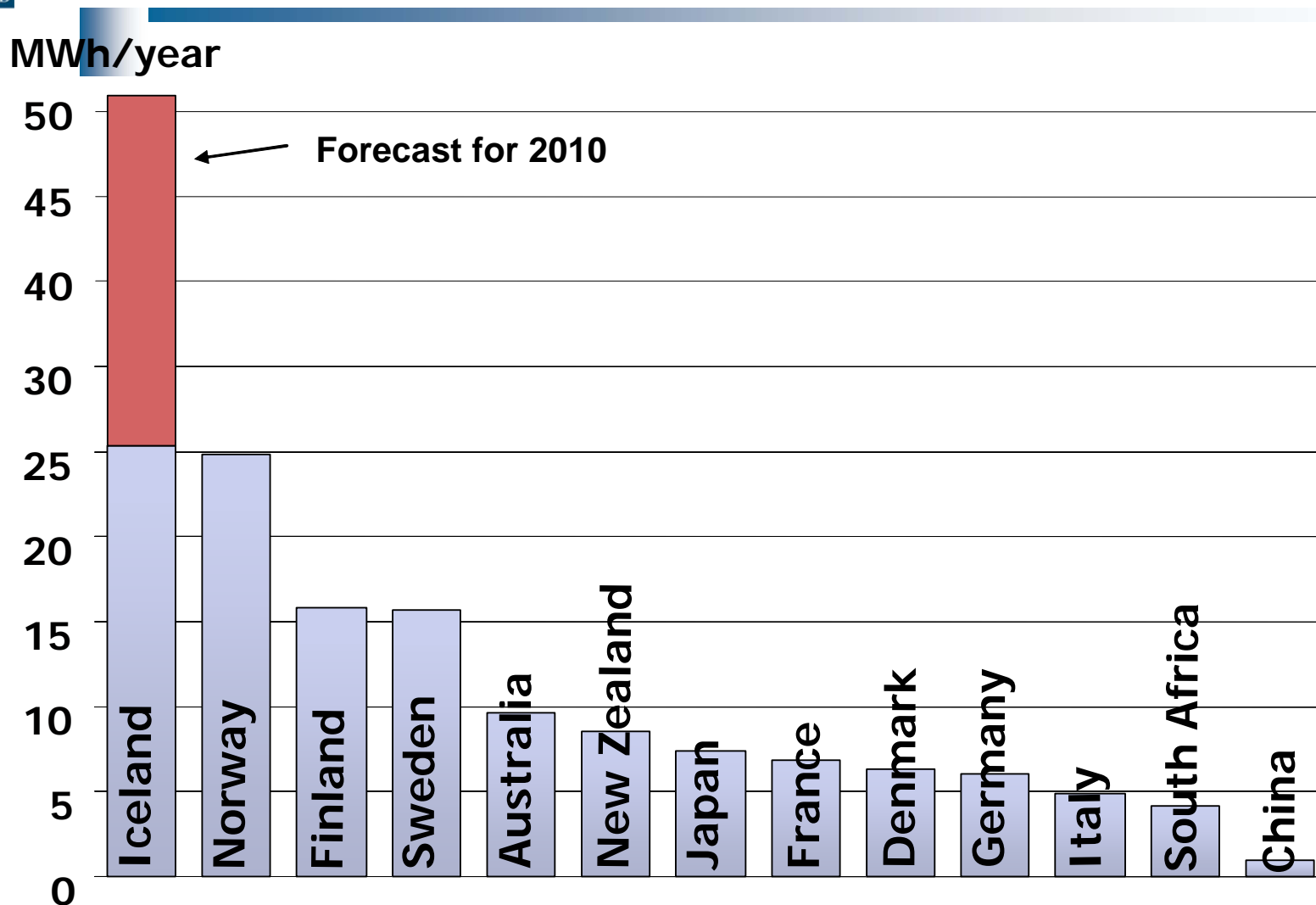
# Total resource capacity and estimated electricity generation 2005 and 2010





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# Electricity generation per capita in 2003 in several countries

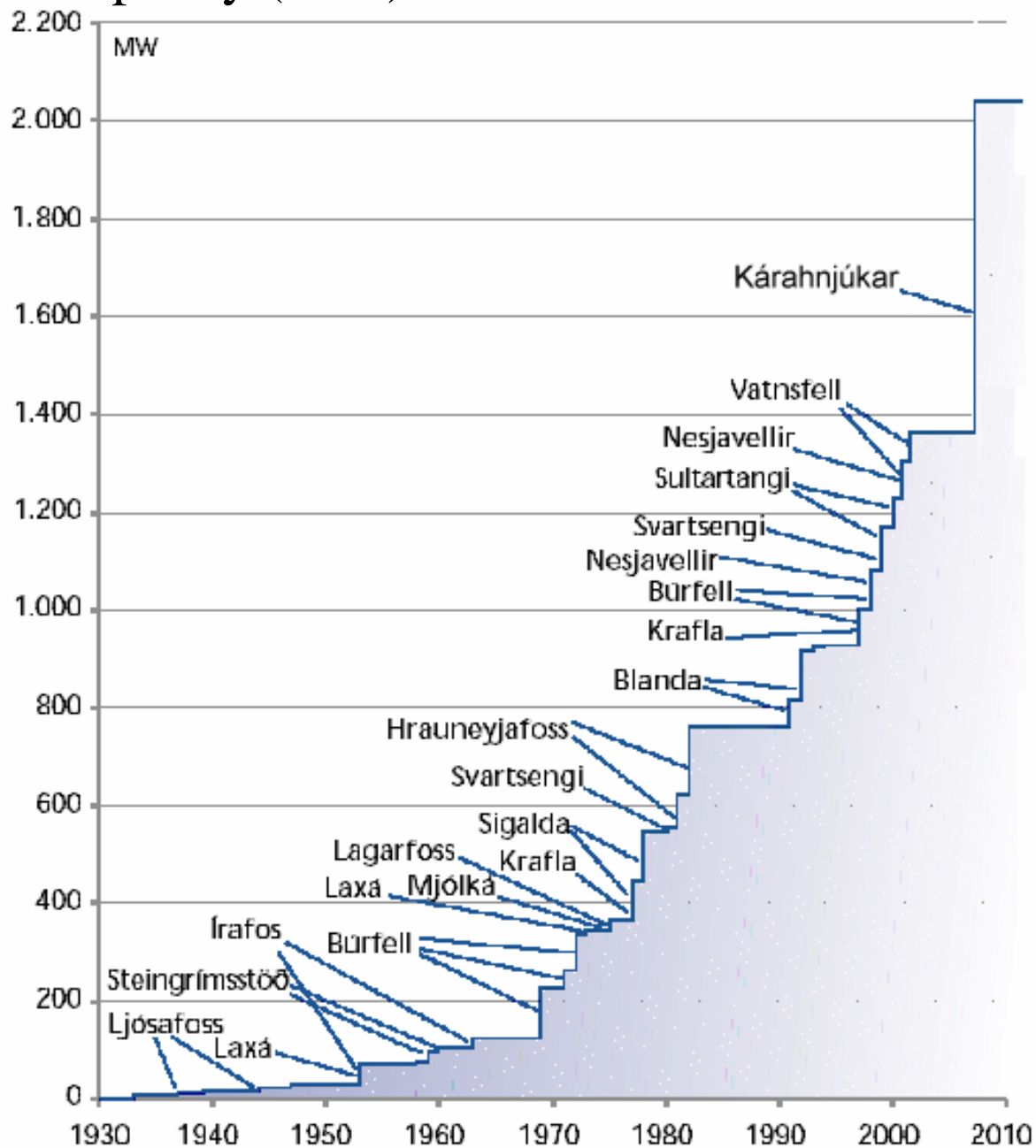




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# Installed capacity (MW)

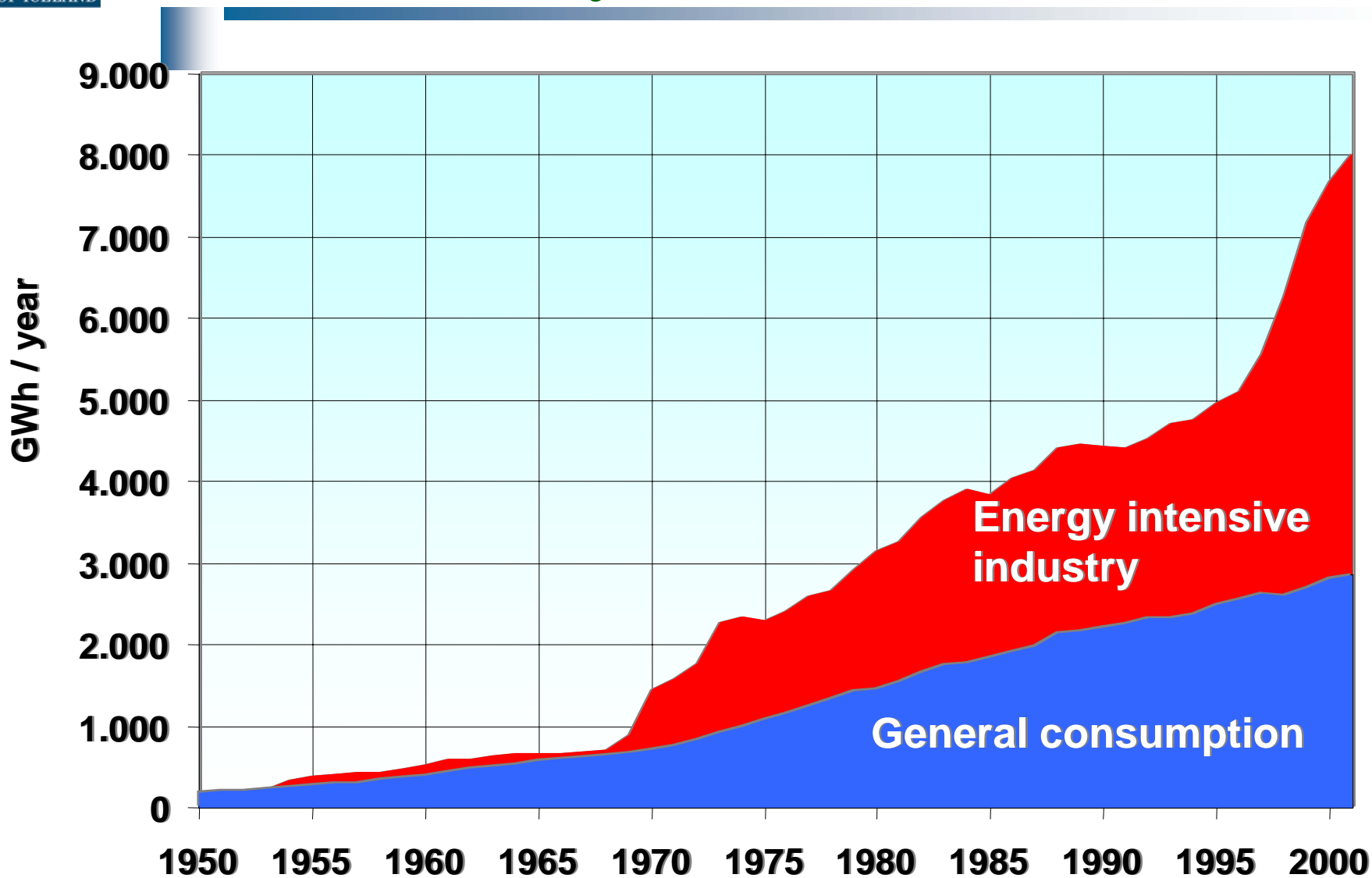
The rapid growth of hydro and geothermal electricity installed electrical capacity (MW) in recent decades





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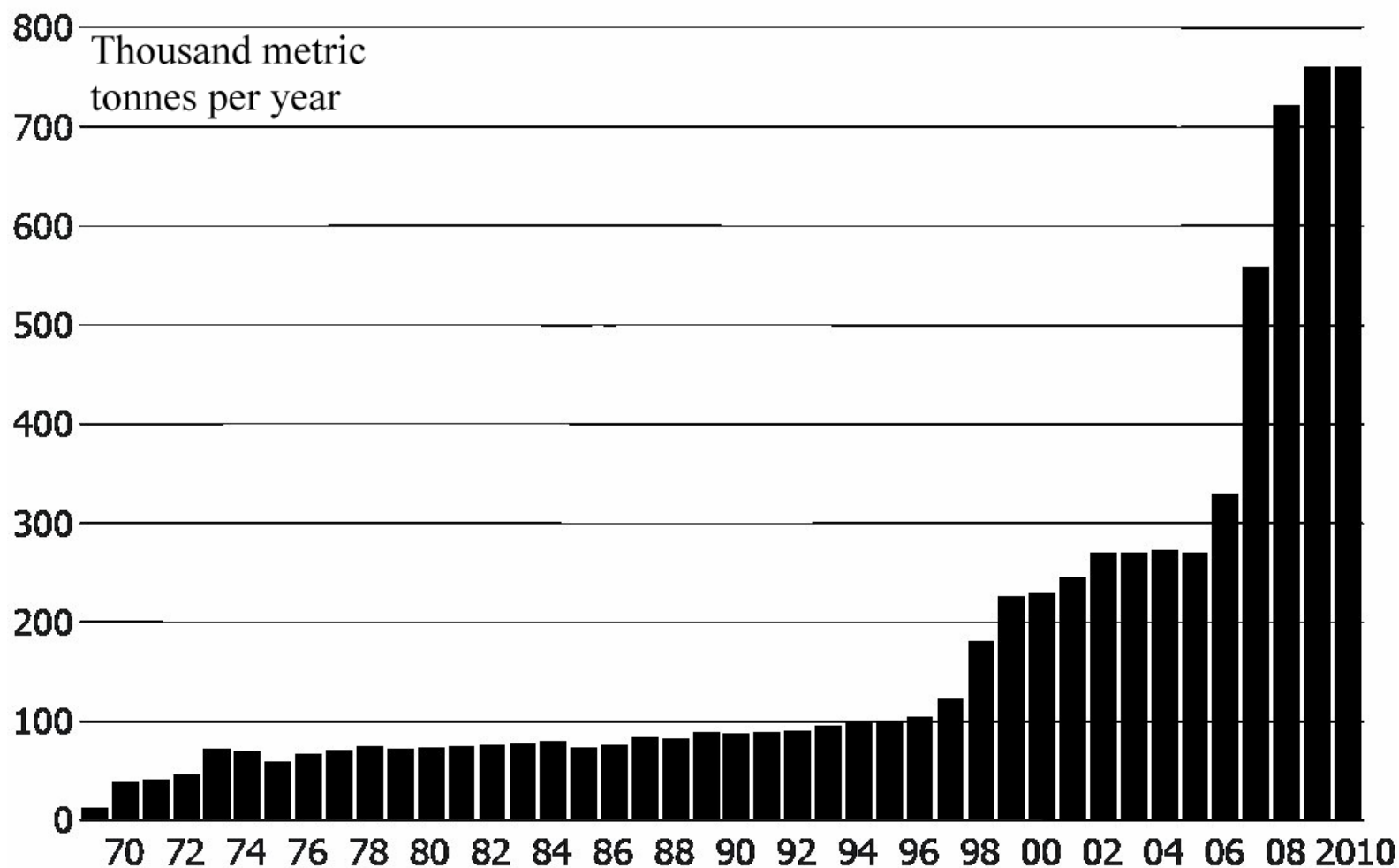
# Historical general and energy intensive industry load 1950-2002





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# Aluminium Production in Iceland 1969-2010

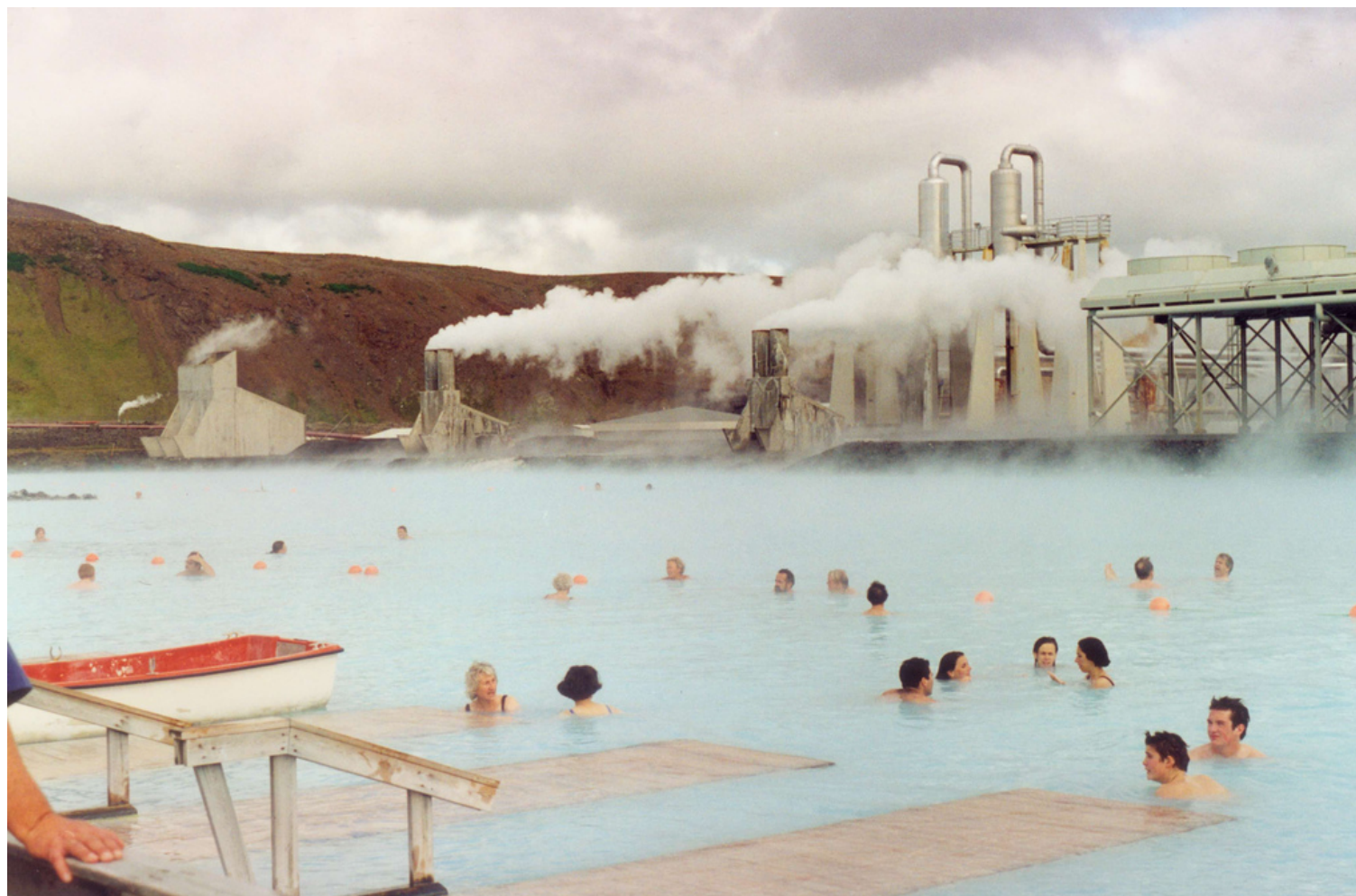






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# Example of a Spin-off Operation from Geothermal Generation.





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**Power generation:**

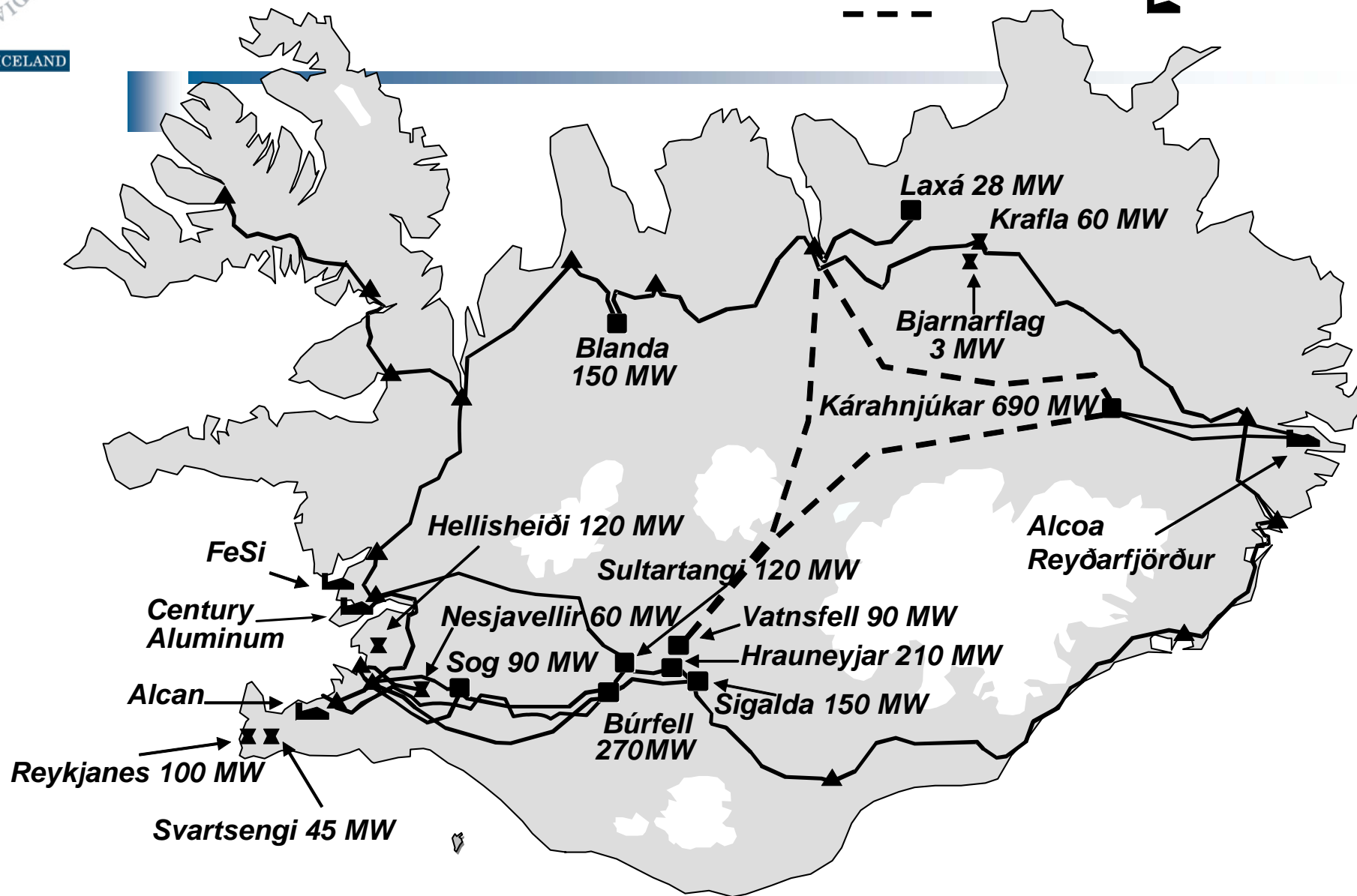
Hydro power

Geothermal

Substation

132/220 kV  
Transmission  
Lines (existing/future)

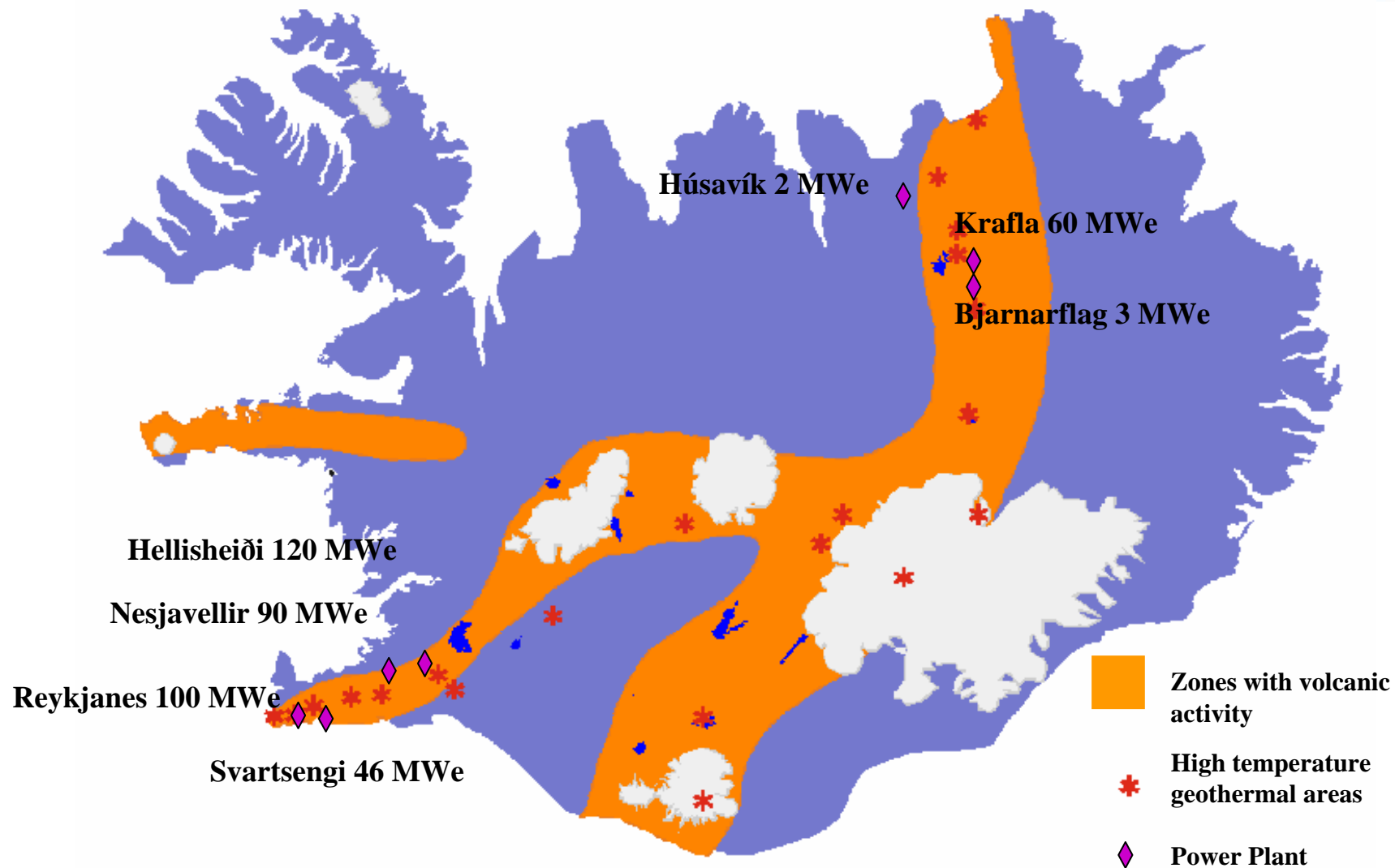
Energy  
Intensive  
Industry (EII)





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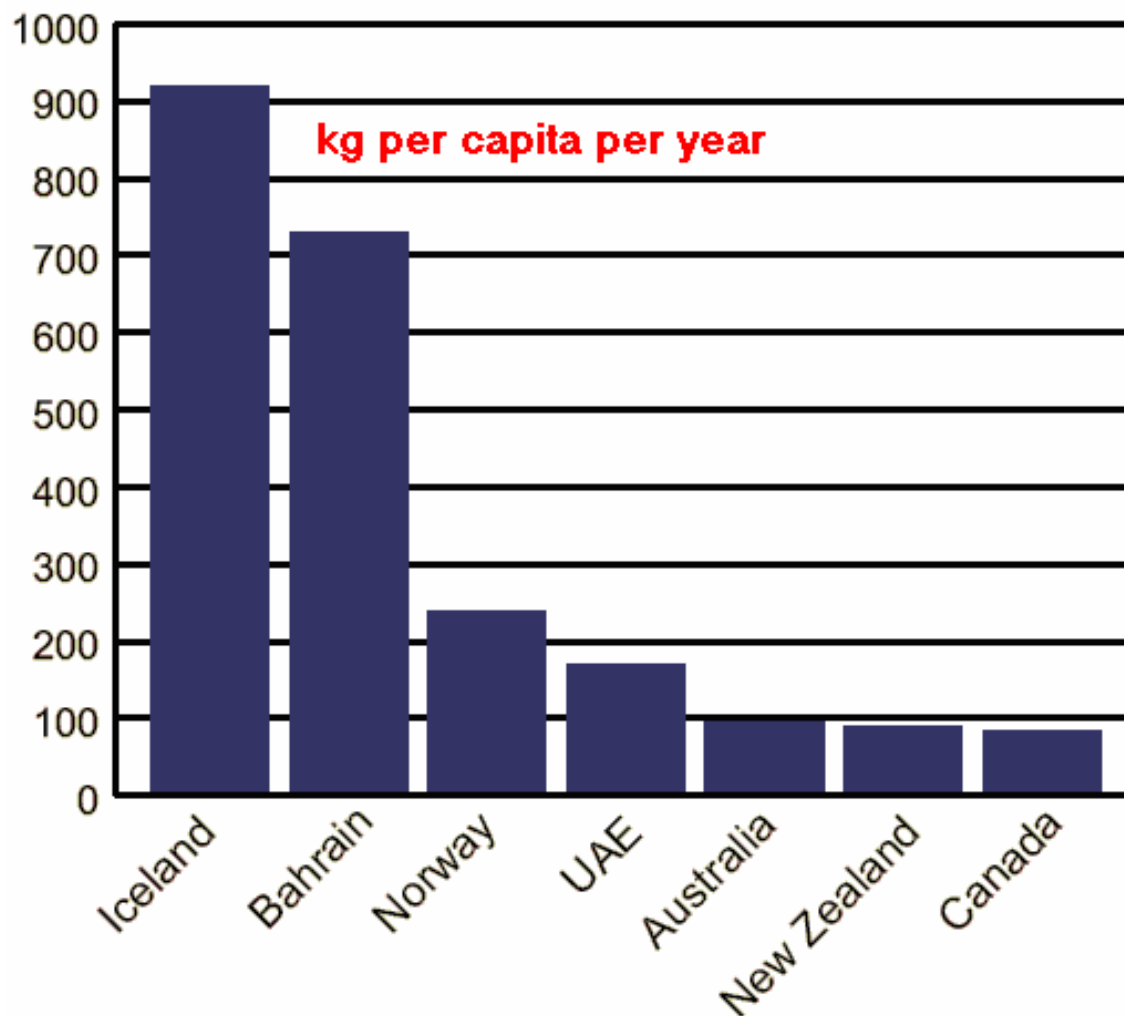
# Principal Geothermal Areas





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# 2001 Iceland has the highest aluminium production in the world per capita





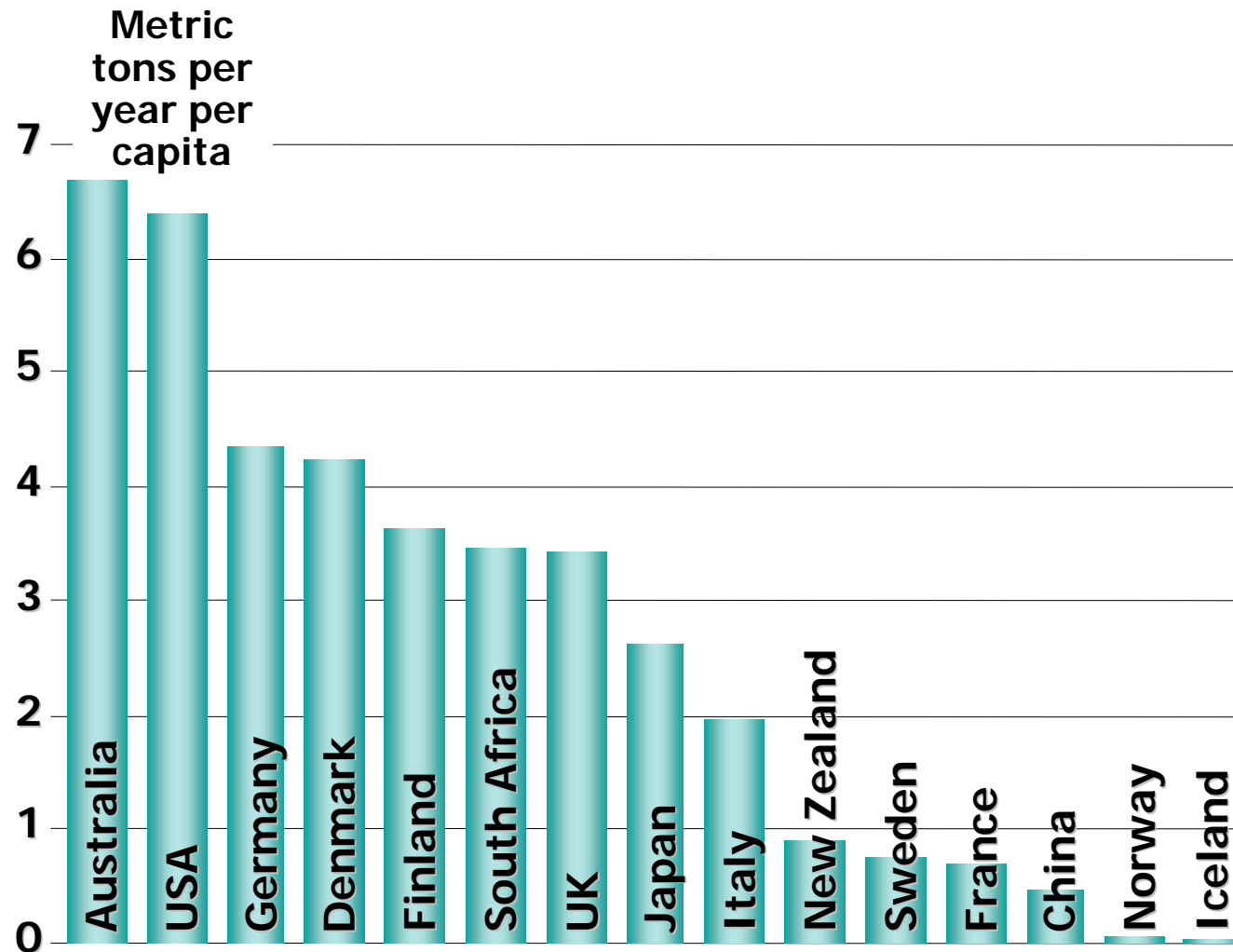
# Characteristics and ownership of the Icelandic renewable energy system

| Power System Layer                        | Market model             | Ownership                |
|---|--------------------------|--------------------------|
| Resources/Water rights                    | Competition /Monopoly??? | Private/Public??         |
| ↕ Undefined price signals/ Appropriation? |                          |                          |
| Generation                                | Competition              | Public (State/Municipal) |
| ↕ Explicit prices (€kWh)                  |                          |                          |
| Transmission                              | Monopoly                 | Public (State/Municipal) |
| ↕ Explicit prices (€kWh)                  |                          |                          |
| Distribution                              | Monopoly                 | Public (Municipal)       |
| ↕ Explicit prices (€kWh)                  |                          |                          |
| Sales                                     | Competition              | Public (State/Municipal) |
| ↕ Explicit prices (€kWh)                  |                          |                          |



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# The Estimated CO<sub>2</sub> Emissions Per Capita from Electricity Generation





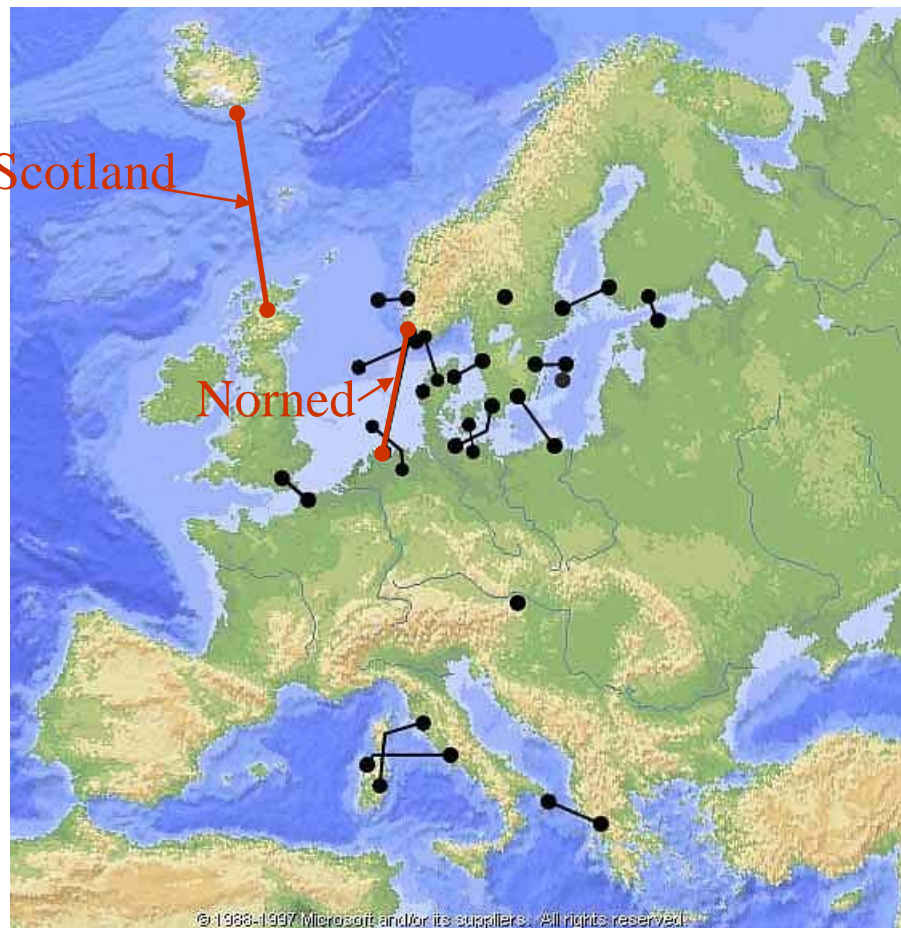
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# European HVDC submarine interconnectors

- Norned was commissioned in May 2008
- Iceland-Scotland (approximately 950 km).
- **Norned is about 2/3 of the length of and Iceland-Scotland interconnection**  
**Norned was taken into operation in May 2008!!**

Iceland-Scotland

Norned



<http://www.statnett.no/default.aspx?ChannelID=1169&DocumentID=12443>

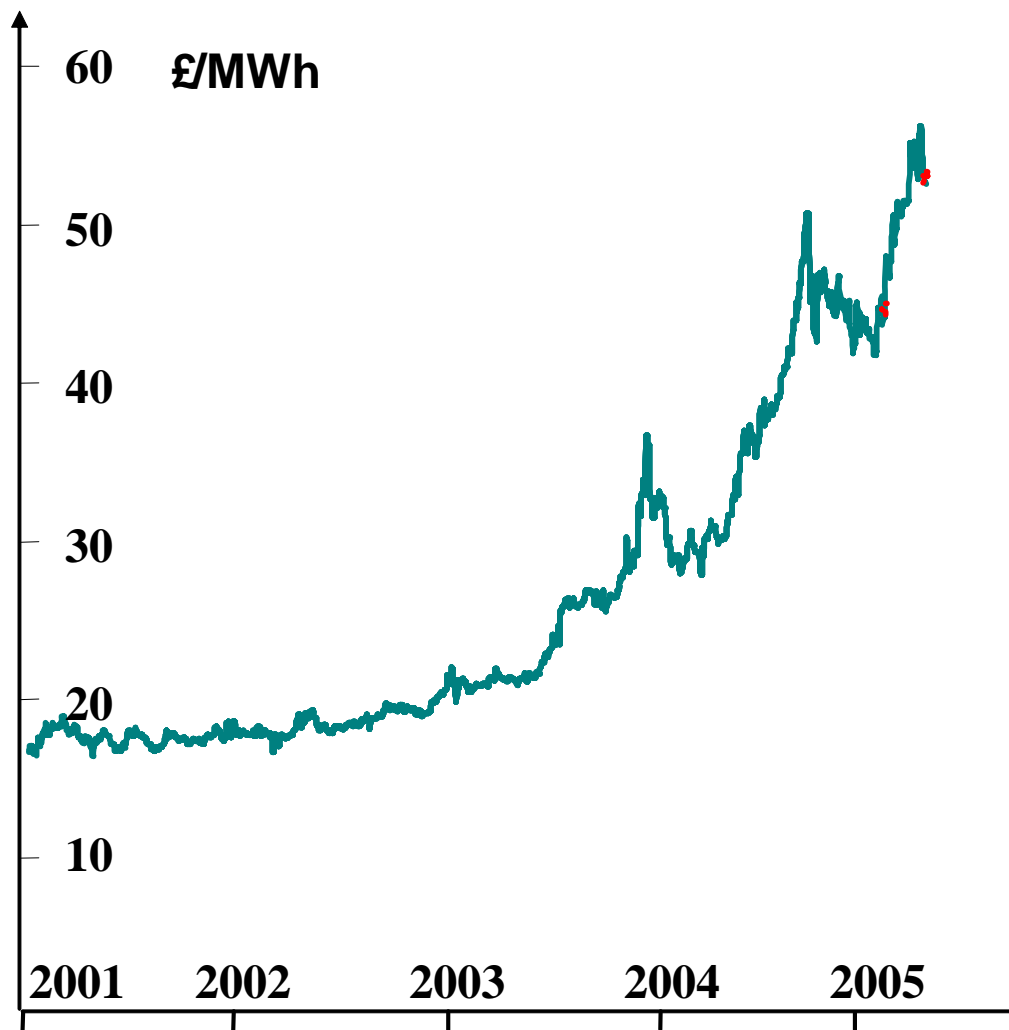
HVDC Transmission: Part of the Energy Solution?

<http://cohesion.rice.edu/CentersAndInst/CNST/emplibrary/Hartley%2004May03%20NanoTechConf.ppt>



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# Wholesale Electricity Prices in the UK 2001-2006



Note: UK Wholesale electricity and natural gas forward prices  
Source: Heren Energy report  
Exchange rate: £/€1.50

[http://ec.europa.eu/enterprise/environment/hlg/docs/group\\_3/goldsmith.ppt](http://ec.europa.eu/enterprise/environment/hlg/docs/group_3/goldsmith.ppt)





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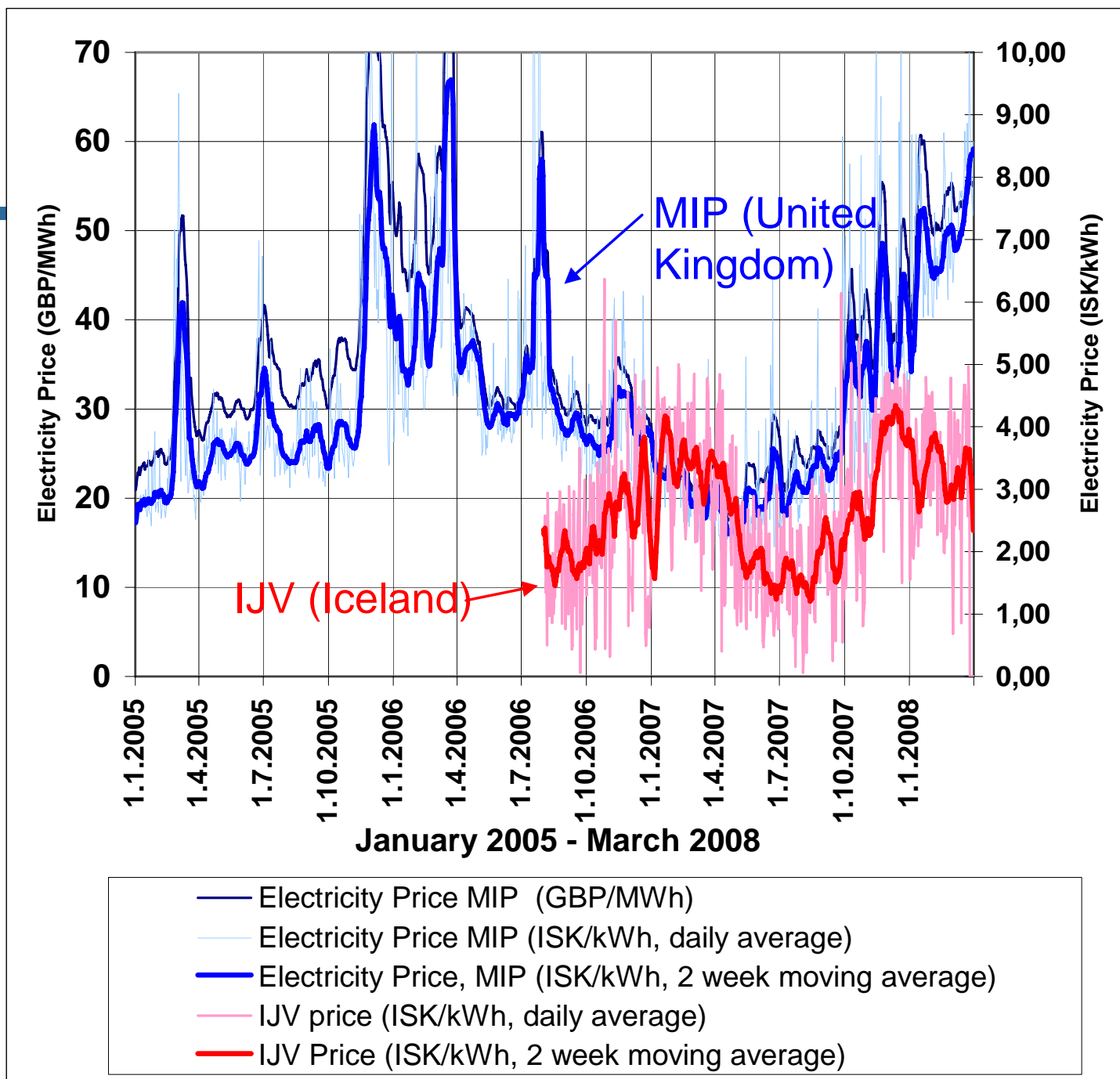
# Wholesale Electricity Prices in the UK (MIP) and in Iceland (IJV)

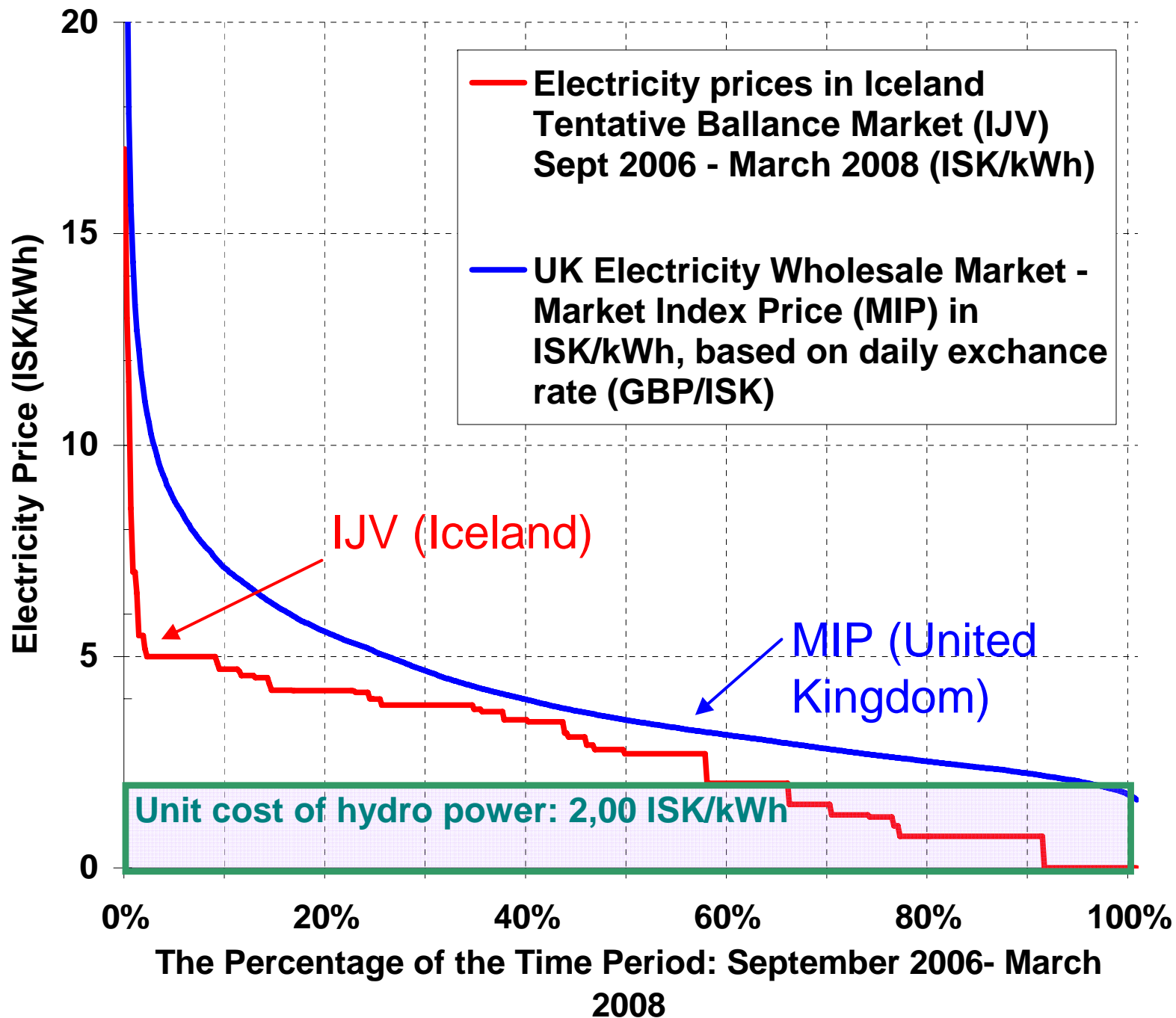
Sources:

[http://www.elxon.co.uk/documents/Market\\_Data/Market\\_Index\\_Data\\_-\\_Price\\_and\\_Volume\\_Data/Market\\_Index\\_Price\\_and\\_volume.xls](http://www.elxon.co.uk/documents/Market_Data/Market_Index_Data_-_Price_and_Volume_Data/Market_Index_Price_and_volume.xls)

and:

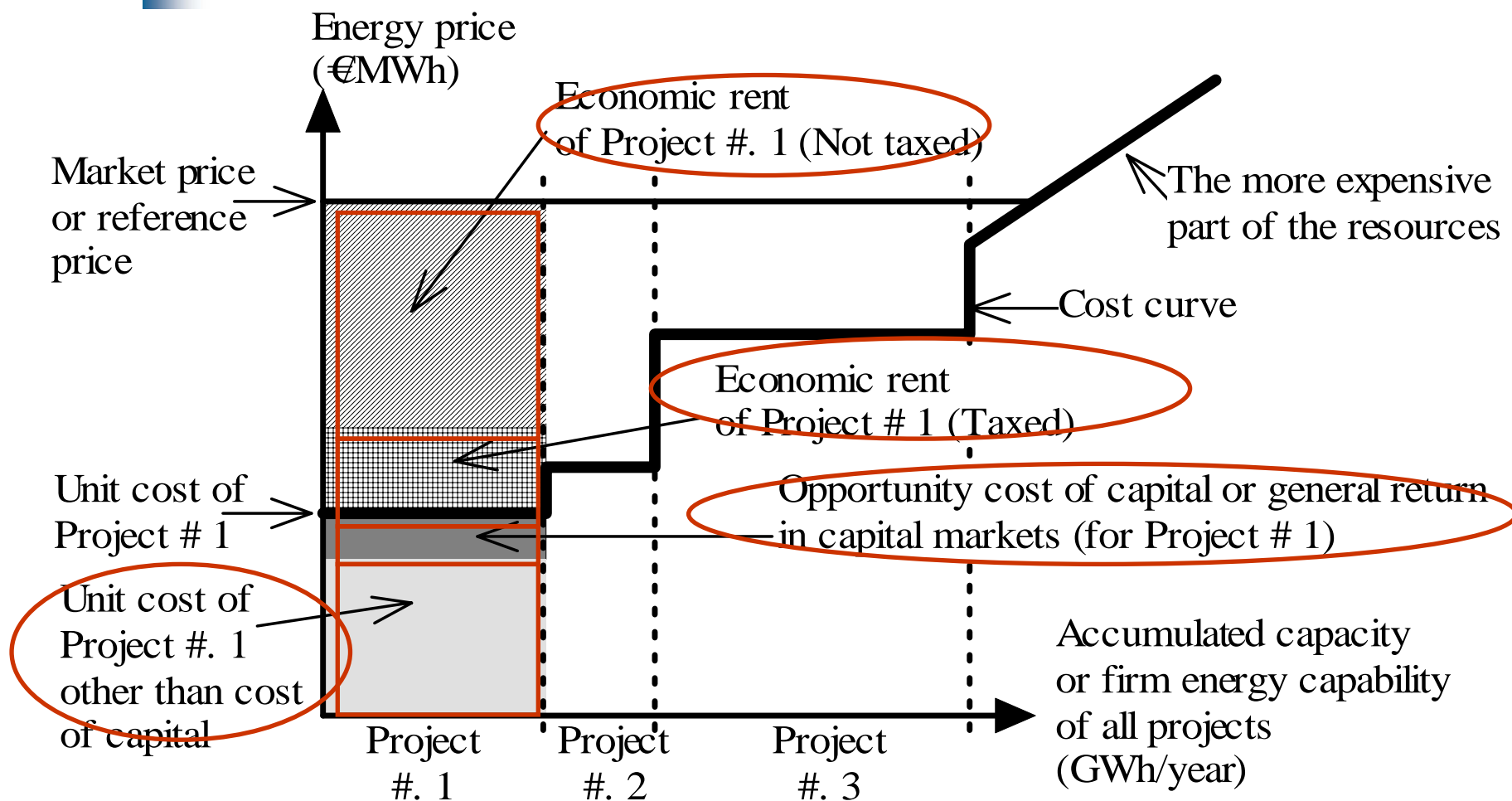
<http://landsnet.is/index.aspx?GroupId=254>







# Economic Rent (ER) for a Sequence of Hydro or Geothermal Projects



# Resource overview

| Project Type | Project No. | Project Name            | Firm Energy (Gwh/year) | Unit Investment Cost (US\$/MWh/year) | Investment Cost (Million US\$) | Unit Investment Cost (US\$/MWh) w/interest: |             |             | Operations Cost (US\$/MWh) | Total Unit Cost (US\$/MWh) w/interest: |      |      |
|--------------|-------------|-------------------------|------------------------|--------------------------------------|--------------------------------|---|-------------|-------------|----------------------------|--|------|------|
|              |             |                         |                        |                                      |                                | 5%  | 6%          | 7%          |                            | 5%                                     | 6%   | 7%   |
| Hydro        | 7           | Jökulsá á Fjöllum       | 4000                   | 264,7                                | 1.059                          | 15,4  | 17,6        | 19,9        | 5,3                        | 20,7                                   | 22,9 | 25,2 |
| Hydro        | 8           | Kárahnjúkavirkjun       | 4670                   | 287,8                                | 1.344                          | 16,8  | 19,1        | 21,6        | 5,8                        | 22,5                                   | 24,9 | 27,3 |
| Hydro        | 9           | Fljótsdalsvirkjun       | 1390                   | 271,9                                | 378                            | 15,8  | 18,1        | 20,4        | 5,4                        | 21,3                                   | 23,5 | 25,8 |
| Hydro        | 14          | Skaftárveita            | 450                    | 118,0                                | 53                             | 6,9   | 7,8         | 8,8         | 2,4                        | 9,2                                    | 10,2 | 11,2 |
| Geotherm.    | 30          | Reykjanes               | 840                    | 240,3                                | 202                            | 14,0  | 16,0        | 18,0        | 7,2                        | 21,2                                   | 23,2 | 25,2 |
| Hydro        | 10          | Skaftárvirkjun          | 904                    | 295,0                                | 267                            | 17,2  | 19,6        | 22,1        | 5,9                        | 23,1                                   | 25,5 | 28,0 |
| Geotherm.    | 43          | Hágöngusvæði            | 840                    | 254,7                                | 214                            | 14,8  | 16,9        | 19,1        | 7,6                        | 22,5                                   | 24,6 | 26,7 |
| Geotherm.    | 52          | Krafla- vestursvæði     | 840                    | 256,1                                | 215                            | 14,9  | 17,0        | 19,2        | 7,7                        | 22,6                                   | 24,7 | 26,9 |
| Hydro        | 15          | Norðlingaölduveita      | 650                    | 234,5                                | 152                            | 13,7  | 15,6        | 17,6        | 4,7                        | 18,4                                   | 20,3 | 22,3 |
| Hydro        | 17          | Núpsvirkjun a           | 1001                   | 326,6                                | 327                            | 19,0  | 21,7        | 24,5        | 6,5                        | 25,6                                   | 28,2 | 31,0 |
| Hydro        | 18          | Núpsvirkjun b           | 1019                   | 332,4                                | 339                            | 19,4  | 22,1        | 24,9        | 6,6                        | 26,0                                   | 28,7 | 31,6 |
| Geotherm.    | x           | Various geo-projects    | 14280                  | 273,4                                | 3.904                          | 15,9  | 18,2        | 20,5        | 8,2                        | 24,1                                   | 26,4 | 28,7 |
| Hydro        | 19          | Urriðafossvirkjun       | 920                    | 333,8                                | 307                            | 19,5  | 22,2        | 25,0        | 6,7                        | 26,1                                   | 28,9 | 31,7 |
| Hydro        | 5           | Hrafnabjargarvirkjun a  | 575                    | 305,0                                | 175                            | 17,8  | 20,3        | 22,9        | 6,1                        | 23,9                                   | 26,4 | 29,0 |
| Geotherm.    | 50          | Bjarnarflag             | 560                    | 263,3                                | 147                            | 15,3  | 17,5        | 19,8        | 7,9                        | 23,2                                   | 25,4 | 27,6 |
| Hydro        | 1           | Skatastaðavirkjun a     | 1046                   | 352,5                                | 369                            | 20,5  | 23,4        | 26,4        | 7,1                        | 27,6                                   | 30,5 | 33,5 |
| Geotherm.    | 39          | Nesjavellir, stækkun    | 210                    | 171,2                                | 36                             | 10,0  | 11,4        | 12,8        | 5,1                        | 15,1                                   | 16,5 | 18,0 |
| Hydro        | 2           | Skatastaðavirkjun b     | 1290                   | 359,7                                | 464                            | 21,0  | 23,9        | 27,0        | 7,2                        | 28,2                                   | 31,1 | 34,2 |
| Hydro        | 16          | Búðarhálsvirkjun        | 630                    | 333,8                                | 210                            | 19,5  | 22,2        | 25,0        | 6,7                        | 26,1                                   | 28,9 | 31,7 |
| Geotherm.    | 51          | Krafla I stækkun        | 280                    | 220,1                                | 62                             | 12,8  | 14,6        | 16,5        | 6,6                        | 19,4                                   | 21,2 | 23,1 |
| Hydro        | 6           | Hrafnabjargavirkjun b   | 618                    | 335,3                                | 207                            | 19,5  | 22,3        | 25,1        | 6,7                        | 26,2                                   | 29,0 | 31,9 |
| Hydro        | 13          | Markarsfljótsvirkjun b  | 855                    | 351,1                                | 300                            | 20,5  | 23,3        | 26,3        | 7,0                        | 27,5                                   | 30,4 | 33,4 |
| Hydro        | 11          | Hólmsársvirkjun         | 438                    | 316,5                                | 139                            | 18,4  | 21,0        | 23,7        | 6,3                        | 24,8                                   | 27,4 | 30,1 |
| Hydro        | 12          | Markarsfljótsvirkjun a  | 735                    | 341,0                                | 251                            | 19,9  | 22,7        | 25,6        | 6,8                        | 26,7                                   | 29,5 | 32,4 |
| Geotherm.    | 31          | Svartsengi,             | 140                    | 154,0                                | 22                             | 9,0   | 10,2        | 11,5        | 4,6                        | 13,6                                   | 14,9 | 16,2 |
| Hydro        | 3           | Villinganesvirkjun      | 190                    | 351,1                                | 67                             | 20,5  | 23,3        | 26,3        | 7,0                        | 27,5                                   | 30,4 | 33,4 |
| Hydro        | 4           | Fljótshnúksvirkjun      | 405                    | 579,9                                | 235                            | 33,8  | 38,5        | 43,5        | 11,6                       | 45,4                                   | 50,1 | 55,1 |
| Hydro        |             | <b>Total Hydro</b>      | <b>21.786 GWh/year</b> |                                      | <b>6.642</b>                   | <b>17,8</b>                                 | <b>20,3</b> | <b>22,9</b> |                            |  |      |      |
| Geotherm.    |             | <b>Total Geothermal</b> | <b>17.990 GWh/year</b> |                                      | <b>4.801</b>                   | <b>15,6</b>                                 | <b>17,7</b> | <b>20,0</b> |                            |  |      |      |
| Total        |             | <b>TOTAL/AVERAGE</b>    | <b>39.776 GWh/year</b> |                                      | <b>11.444</b>                  | <b>16,8</b>                                 | <b>19,1</b> | <b>21,6</b> |                            |  |      |      |

•Forsendur og fyrirvarar:

- Óviss stofn- og rekstrar- kostnaður virkjana
- Óviss orkugeta
- Byggt á virkjunarkostum í *tílraunamati*
- Rammaáætlunar (1. hluti)
- Sumar virkjanir útiloka aðrar virkjanir
- Kárahnjúka- virkjun hér meðtalin

# ER estimate (2)

Market reference: 35.9 US\$/MWh or 2,50 ISK/kWh

| Project No.  | Resource Rent per MWh (US\$/MWh) with interest |              |             | Annual Resource Rent ( Million US\$/year) |            |            | Discounted value of resource rent |              |              |                   |            |            |
|--------------|--|--------------|-------------|---|------------|------------|-----------------------------------|--------------|--------------|-------------------|------------|------------|
|              | 5%   | 6%           | 7%          | 5%  | 6%         | 7%         | Million US\$                      |              |              | % of Investm cost |            |            |
|              |  |              |             |   |            |            | 5%                                | 6%           | 7%           | 5%                | 6%         | 7%         |
| 7            | 15.25  | 13.08        | 10.82       | 60.99                                     | 52.32      | 43.27      | 1046.5                            | 787.3        | 576.9        | 99%               | 74%        | 54%        |
| 8            | 13.45  | 11.09        | 8.63        | 62.79                                     | 51.79      | 40.30      | 1077.4                            | 779.3        | 537.3        | 80%               | 58%        | 40%        |
| 9            | 14.68  | 12.46        | 10.13       | 20.41                                     | 17.32      | 14.09      | 350.2                             | 260.6        | 187.8        | 93%               | 69%        | 50%        |
| 14           | 26.74  | 25.77        | 24.76       | 12.03                                     | 11.60      | 11.14      | 206.4                             | 174.5        | 148.6        | 389%              | 329%       | 280%       |
| 30           | 14.76  | 12.79        | 10.74       | 12.40                                     | 10.75      | 9.02       | 212.7                             | 161.7        | 120.3        | 105%              | 80%        | 60%        |
| 10           | 12.88  | 10.47        | 7.95        | 11.65                                     | 9.46       | 7.18       | 199.8                             | 142.4        | 95.8         | 75%               | 53%        | 36%        |
| 43           | 13.49  | 11.40        | 9.23        | 11.33                                     | 9.58       | 7.75       | 194.4                             | 144.1        | 103.3        | 91%               | 67%        | 48%        |
| 52           | 13.36  | 11.27        | 9.08        | 11.22                                     | 9.46       | 7.62       | 192.6                             | 142.4        | 101.6        | 90%               | 66%        | 47%        |
| 15           | 17.61  | 15.69        | 13.69       | 11.45                                     | 10.20      | 8.90       | 196.4                             | 153.5        | 118.6        | 129%              | 101%       | 78%        |
| 17           | 10.40  | 7.73         | 4.94        | 10.41                                     | 7.74       | 4.94       | 178.7                             | 116.4        | 65.9         | 55%               | 36%        | 20%        |
| 18           | 9.95   | 7.23         | 4.39        | 10.14                                     | 7.37       | 4.48       | 174.0                             | 110.9        | 59.7         | 51%               | 33%        | 18%        |
| x            | 11.84  | 9.60         | 7.26        | 169.04                                    | 137.09     | 103.73     | 2900.6                            | 2062.8       | 1382.8       | 74%               | 53%        | 35%        |
| 19           | 9.84   | 7.11         | 4.26        | 9.05                                      | 6.54       | 3.92       | 155.4                             | 98.4         | 52.2         | 51%               | 32%        | 17%        |
| 5            | 12.09  | 9.60         | 6.99        | 6.95                                      | 5.52       | 4.02       | 119.3                             | 83.0         | 53.6         | 68%               | 47%        | 31%        |
| 50           | 12.73  | 10.57        | 8.32        | 7.13                                      | 5.92       | 4.66       | 122.3                             | 89.1         | 62.1         | 83%               | 60%        | 42%        |
| 1            | 8.38   | 5.49         | 2.48        | 8.76                                      | 5.74       | 2.59       | 150.3                             | 86.4         | 34.6         | 41%               | 23%        | 9%         |
| 39           | 20.86  | 19.45        | 17.99       | 4.38                                      | 4.09       | 3.78       | 75.2                              | 61.5         | 50.4         | 209%              | 171%       | 140%       |
| 2            | 7.81   | 4.87         | 1.80        | 10.08                                     | 6.28       | 2.32       | 173.0                             | 94.5         | 30.9         | 37%               | 20%        | 7%         |
| 16           | 9.84   | 7.11         | 4.26        | 6.20                                      | 4.48       | 2.68       | 106.4                             | 67.4         | 35.7         | 51%               | 32%        | 17%        |
| 51           | 16.54  | 14.74        | 12.85       | 4.63                                      | 4.13       | 3.60       | 79.5                              | 62.1         | 48.0         | 129%              | 101%       | 78%        |
| 6            | 9.73   | 6.98         | 4.12        | 6.01                                      | 4.32       | 2.55       | 103.2                             | 64.9         | 33.9         | 50%               | 31%        | 16%        |
| 13           | 8.49   | 5.62         | 2.62        | 7.26                                      | 4.80       | 2.24       | 124.5                             | 72.3         | 29.8         | 41%               | 24%        | 10%        |
| 11           | 11.19  | 8.60         | 5.90        | 4.90                                      | 3.77       | 2.58       | 84.1                              | 56.7         | 34.4         | 61%               | 41%        | 25%        |
| 12           | 9.28   | 6.49         | 3.57        | 6.82                                      | 4.77       | 2.63       | 117.0                             | 71.7         | 35.0         | 47%               | 29%        | 14%        |
| 31           | 22.38  | 21.12        | 19.80       | 3.13                                      | 2.96       | 2.77       | 53.8                              | 44.5         | 37.0         | 249%              | 206%       | 171%       |
| 3            | 8.49   | 5.62         | 2.62        | 1.61                                      | 1.07       | 0.50       | 27.7                              | 16.1         | 6.6          | 41%               | 24%        | 10%        |
| 4            | 0.00   | 0.00         | 0.00        | 0.00                                      | 0.00       | 0.00       | 0.0                               | 0.0          | 0.0          | 0%                | 0%         | 0%         |
| <b>HYDRO</b> | <b>12.28</b>                                   | <b>9.87</b>  | <b>7.36</b> | <b>268</b>                                | <b>215</b> | <b>160</b> | <b>4,590</b>                      | <b>3,236</b> | <b>2,137</b> | <b>69%</b>        | <b>49%</b> | <b>32%</b> |
| <b>GEOTH</b> | <b>12.41</b>                                   | <b>10.23</b> | <b>7.95</b> | <b>223</b>                                | <b>184</b> | <b>143</b> | <b>3,831</b>                      | <b>2,768</b> | <b>1,906</b> | <b>80%</b>        | <b>58%</b> | <b>40%</b> |
| <b>TOTAL</b> | <b>12.34</b>                                   | <b>10.03</b> | <b>7.62</b> | <b>491</b>                                | <b>399</b> | <b>303</b> | <b>8,421</b>                      | <b>6,004</b> | <b>4,043</b> | <b>74%</b>        | <b>52%</b> | <b>35%</b> |

## •Forsendur og fyrirvarar:

Nýtingarkostnaður byggður á skýrslu um

Rammaáætlun (1. áfangi)

Uppfært kostnaðarmat orkulindanna

Dæmi úr rammaáætlun, 5. kafla, Tafla 5.8

Líftími mannvirkja: 40 ár

Ársvextir: 5%,6% og 7 %

Verðlag 2003

Árlegur rekstrarkostnaður

Vatnsafl: 1% af stofnkostnaði

Jarðhiti: 3% af stofnkostnaði

Ath. Meðfylgjandi líkan er fyrst og fremst

**tilraunamat eða sýnidæmi um verðmætamat orkulinda**

•Gengi dollara: 69,5 kr/USD

•Sumar virkjanir útiloka aðrar virkjanir,

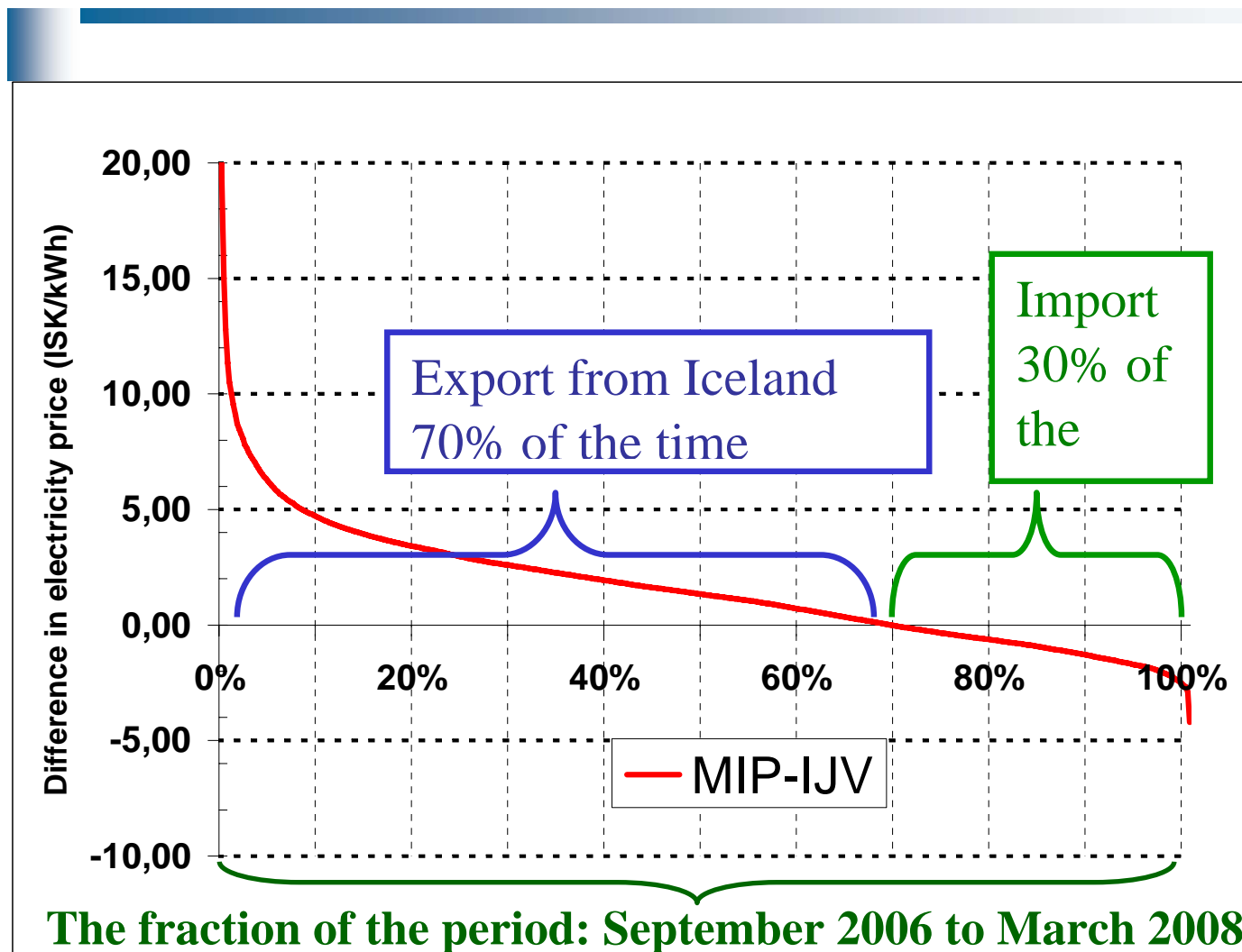
•Óviss stofn- og rekstrar-kostnaður virkjana og orkugeta

•Byggt á virkjunarkostum í *tilraunamati* Rammaáætlunar (1. hluti)

•Gerð verður nánar grein fyrir þessu verðmætamati í á IEEE General Meeting, Pittsburgh, PA, USA í Júlí 2008



# Wholesale Price Differences Between the UK (MIP) and Iceland (IJV) Markets





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## Price Differences in the UK (MIP) Electricity Market and in the Iceland Tentative Wholesale Balance Market (in UK £/MWh)

| Time period          | IJV   | MIP   | MIP-IJV | abs(MIP-IJV)* |
|----------------------|-------|-------|---------|---------------|
| Sept 2006-March 2008 | 21,50 | 34,02 | 12,52   | 18,59         |
| Jan - March 2008     | 26,47 | 57,31 | 30,84   | 31,42         |
| Jan - Dec 2007       | 21,57 | 29,24 | 7,67    | 15,93         |
| Sept - Dec 2006      | 18,57 | 32,45 | 13,89   | 17,83         |

\*) MIP-IJV is calculated when the difference MIP-IJV is positive, otherwise IJV-MIP

Legend:

IJV = Iceland Tentative Wholesale Balance Market

MIP = Market index price = Wholesale price in the UK electricity market



# ER estimate

- **ER = MIP – GenCOST - TxCOST**
  - 6-24 GBP/MWh
- **ER = MIP - IJV - TxCOST**
  - ER = 30-18 = 12 GBP/MWh or ER = 8-12 = -4 GBP/MWh
- **ER = abs(MIP – IJV) – TxCOST.**
  - ER=31-18=13 GBP/MWh or ER=16 - 12=4 GBP/MWh
- **ER = MarkREF-GenCOST**
  - ER= 24 - 16=8 GBP/MWH





# Principal Findings and Conclusions

- Estimation of Economic Rent
- Future HVDC submarine connection with NORNE as a model
- Gas Emission Trading Schemes (GGETS) prices not yet developed
- Arbitrage between markets
- Two way flow with flexible hydro (against wind?)
- Will aluminium smelters go away as prices rise?

Transparencies will be available at the website:

<http://www.hi.is/~egill>

Thank you!

