

# Combustíveis fósseis

Prof. Dr. Eduardo Burin  
Combustíveis e biocombustíveis

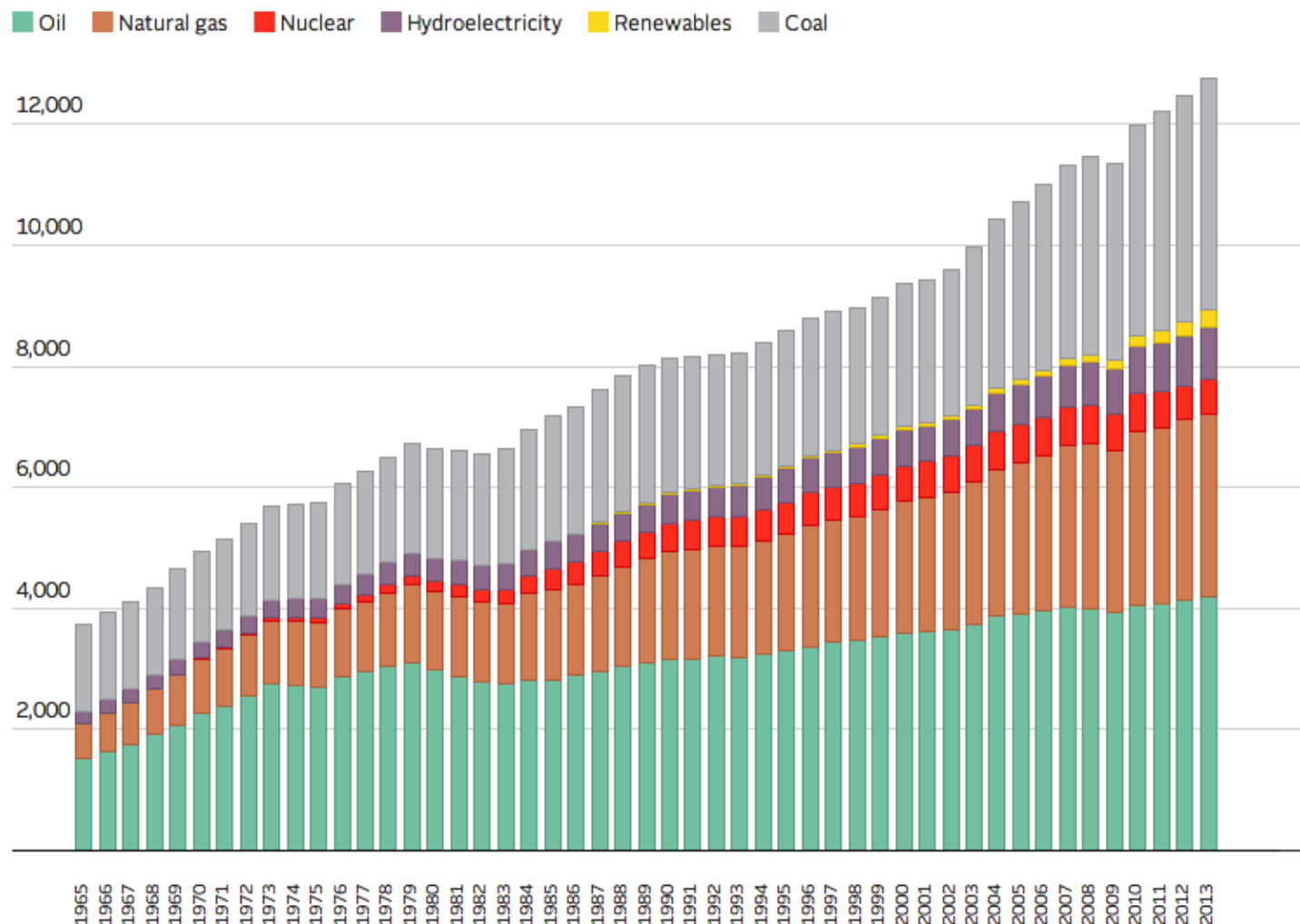
Universidade Federal do Paraná – UFPR  
Setor Palotina



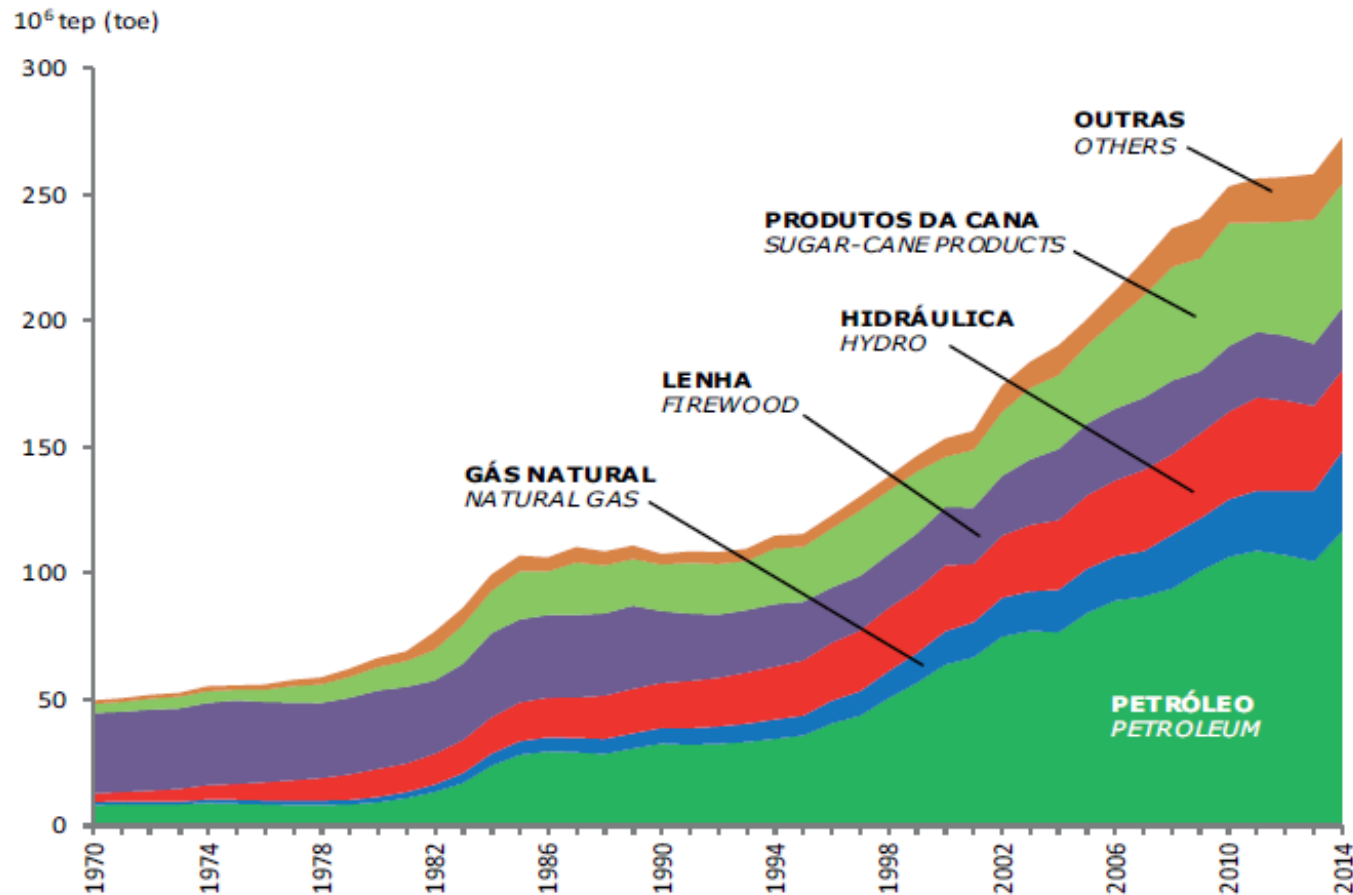
- Parte 1
  - Energia no mundo
  - Formação
  - Características gerais
  - Reservas no mundo e no Brasil
  - Modos de exploração
  
- Parte 2
  - Uso final
  - Impactos ambientais e desafios

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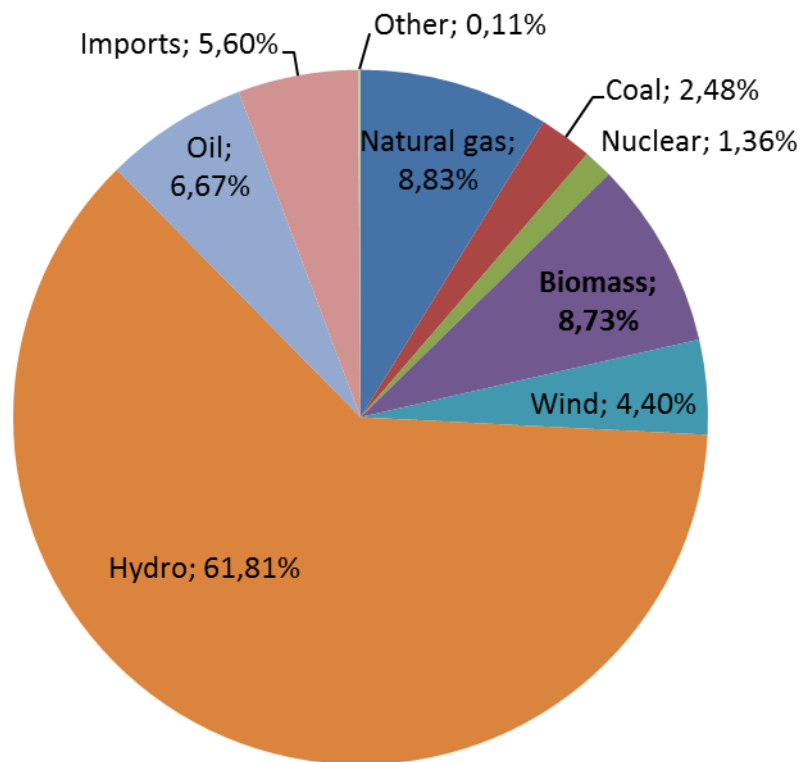
## ■ Oferta de energia primária – mundo [Mtoe]



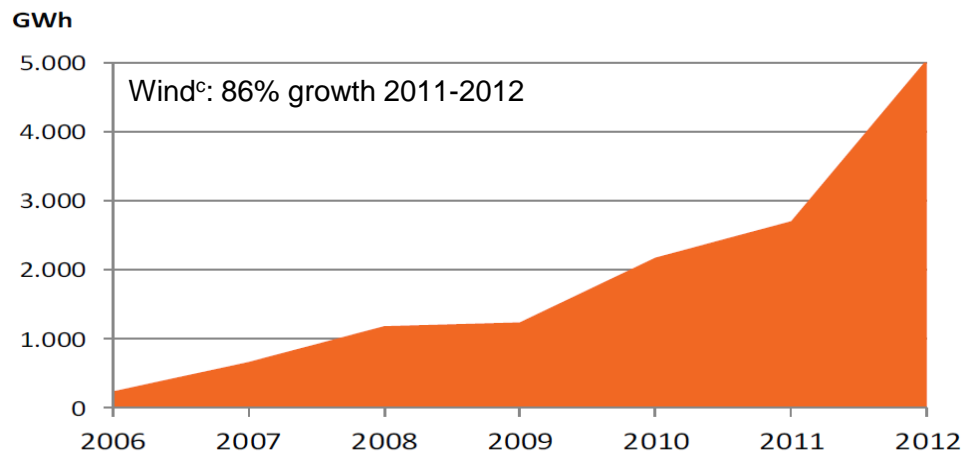
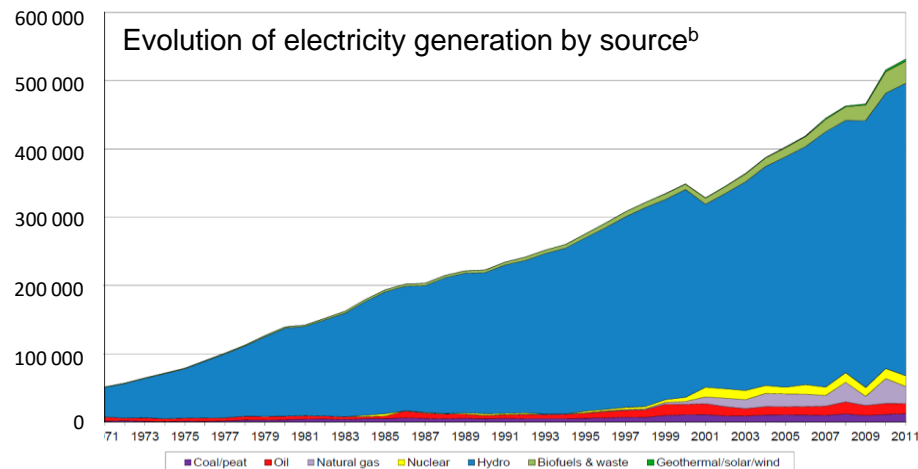
- Oferta de energia primária – Brasil [Mtoe]



## ▪ Energia elétrica – capacidade instalada no Brasil



•Brazil 2015<sup>a</sup>: 146.0 GW

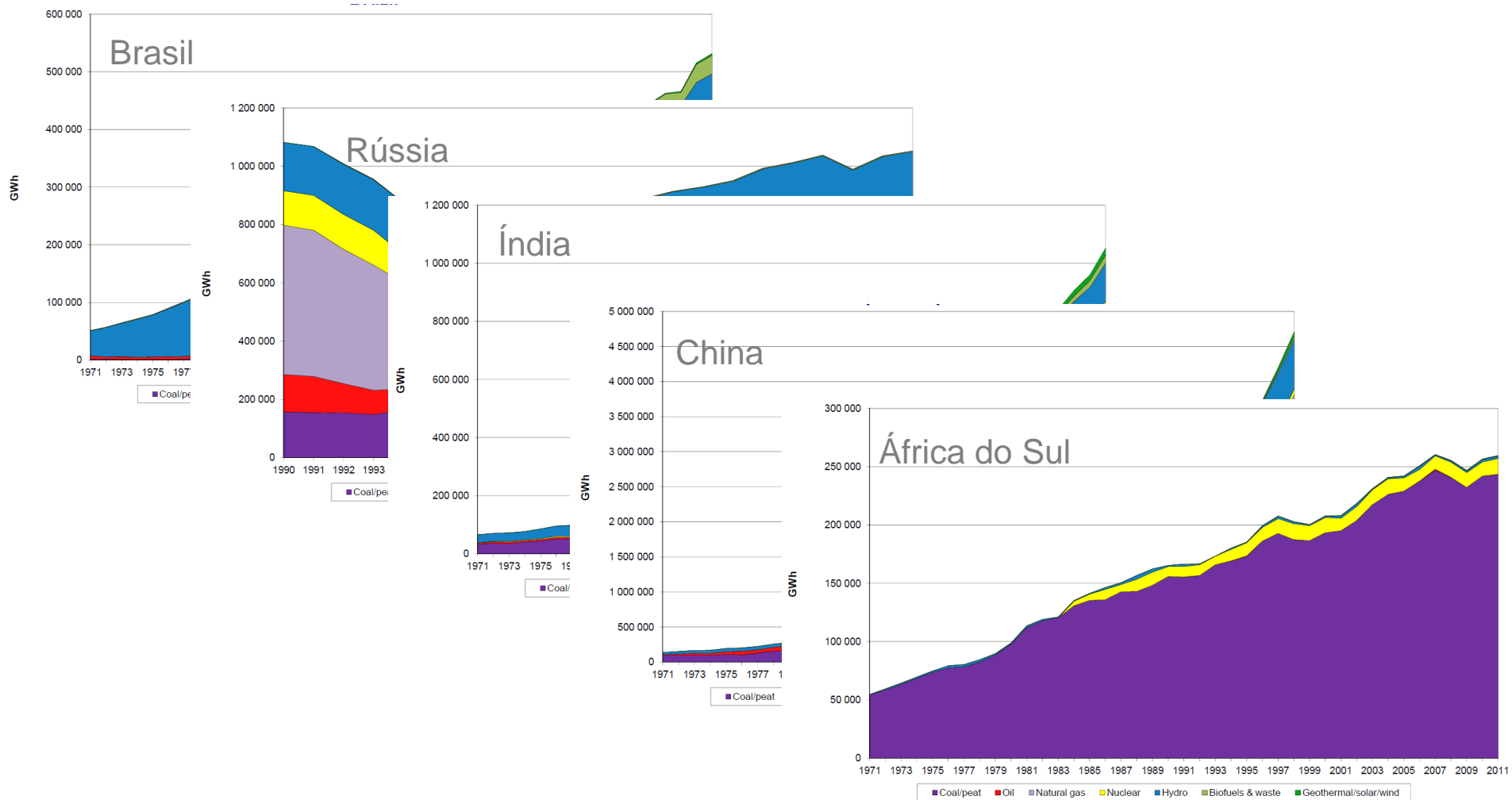


<sup>a</sup>ANEEL. October 2015. In: <<http://www.aneel.gov.br/15.htm>>.

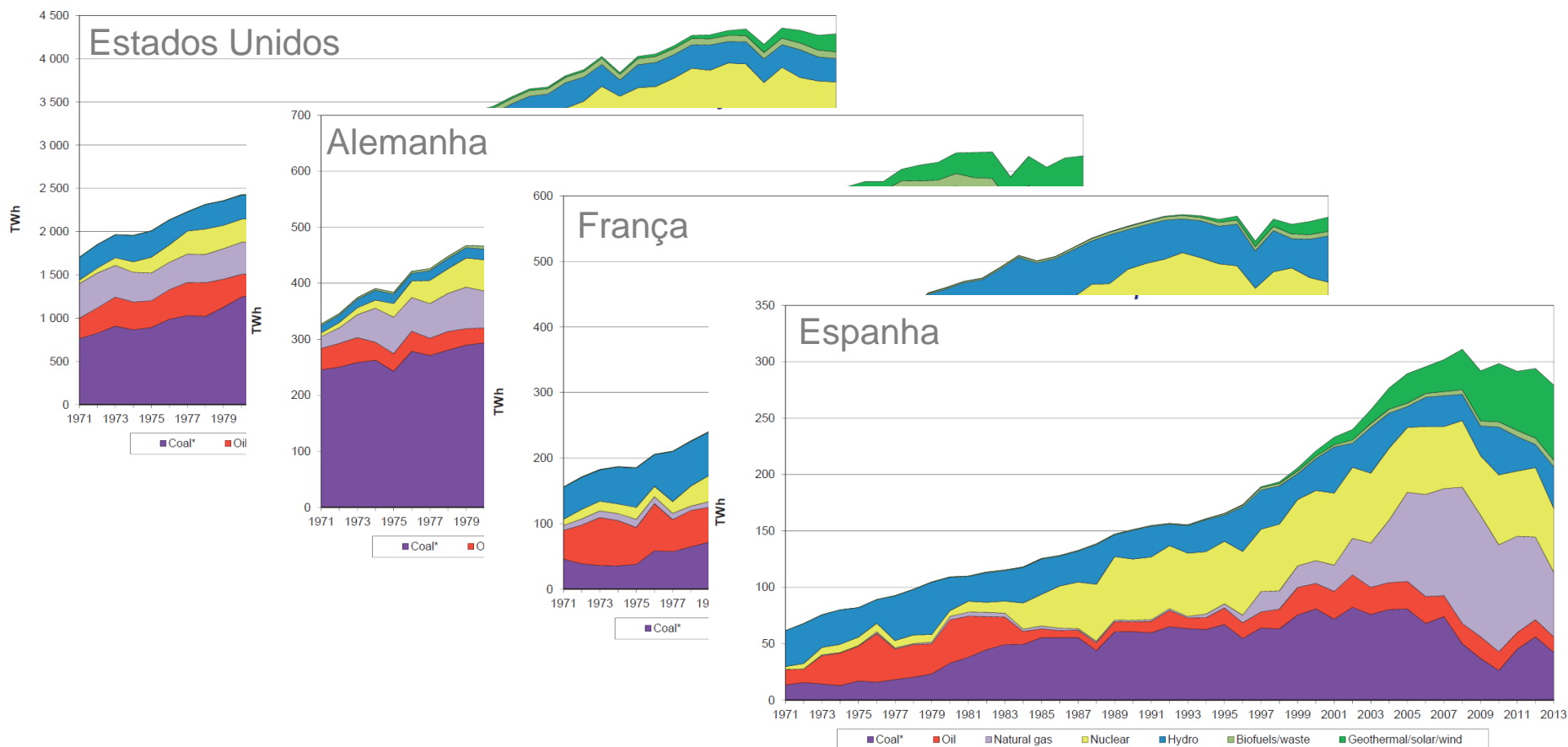
<sup>b</sup>IEA. October 2013. In: <<http://www.iea.org/statistics/>>.

<sup>c</sup>MME. 2013. Balanço energético nacional (2012).

## ■ Energia elétrica – geração por tipo



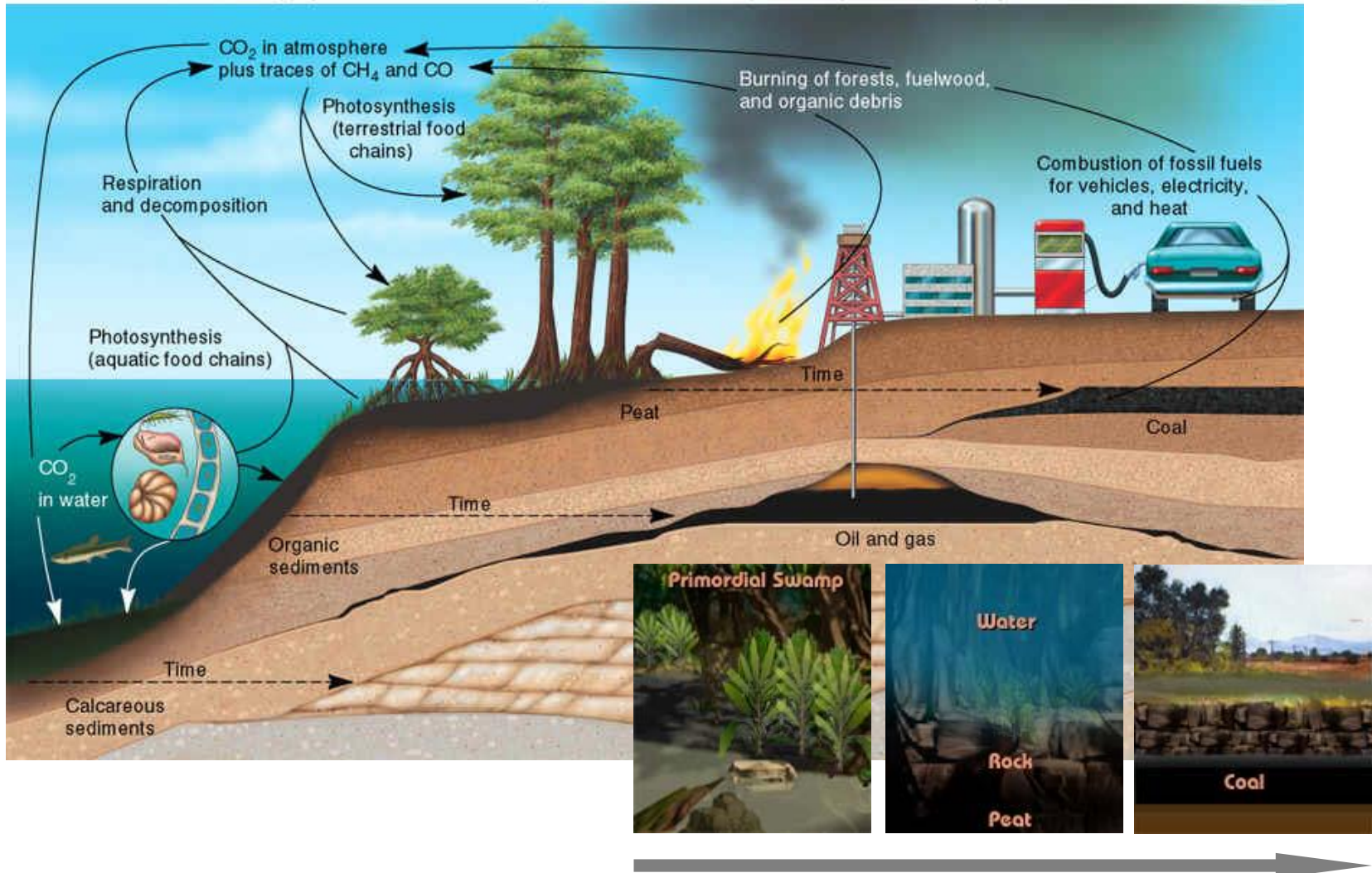
## ■ Energia elétrica – geração por tipo





# Formação

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- Turfa



Campo de turfa<sup>1</sup>

Carvão linhito



<sup>1</sup><http://carlosrabello.org/geografia/biogeografia/flora/turfa/>



## ■ Petróleo

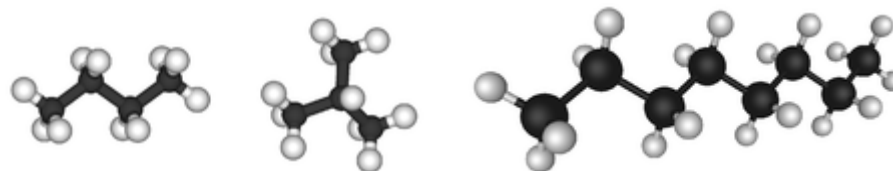
### Composição química [% (m/m)]

Componentes	Faixa
Carbono	83-87
Hidrogênio	10-14
Enxofre	0,05-6,0
Nitrogênio	0,1-2,0
Oxigênio	0,05-1,5
Metais	0,00-0,14

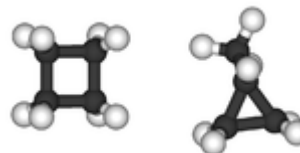
### Composição química [% (m/m)]

Hidrocarbonetos	Média	Faixa
Alcanos	30	15-60
Naftênicos	49	30-60
Aromáticos	15	3-30
Asfálticos	6	Complem.

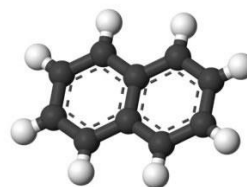
### Alcanos:



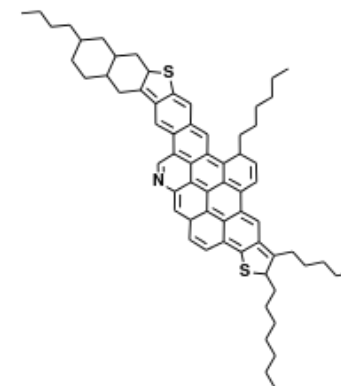
### Naftênicos (cicloalcanos):



### Aromáticos



### Asfaltenos

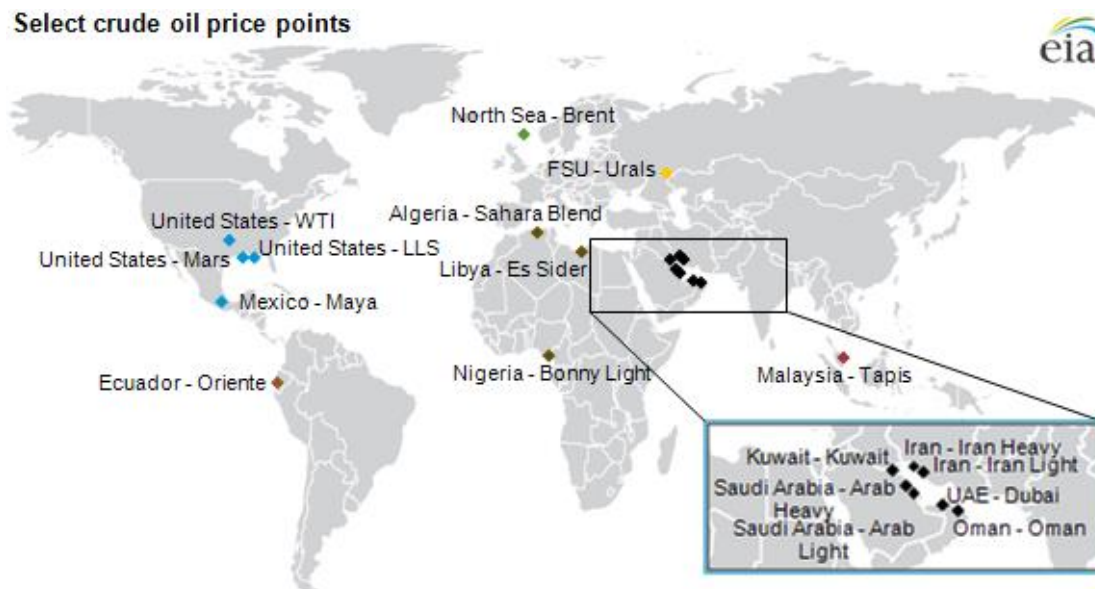


## ■ Petróleo

### Classificação do Petróleo<sup>1</sup>

$$^{\circ}\text{API} = 141,5/\rho - 131,5$$

- a) **Densidade:** Leves (acima de 30 °API); Médios (entre 21 e 30 °API) e Pesados (abaixo de 21 °API);
- b) **Constituintes:** base naftênica; base aromática; base parafínica;
- c) **Local de origem<sup>2</sup>:**

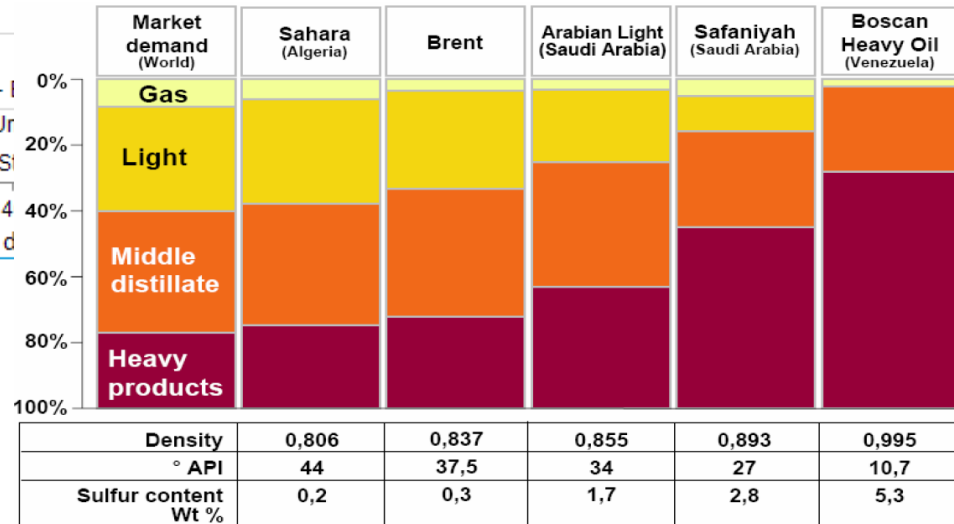
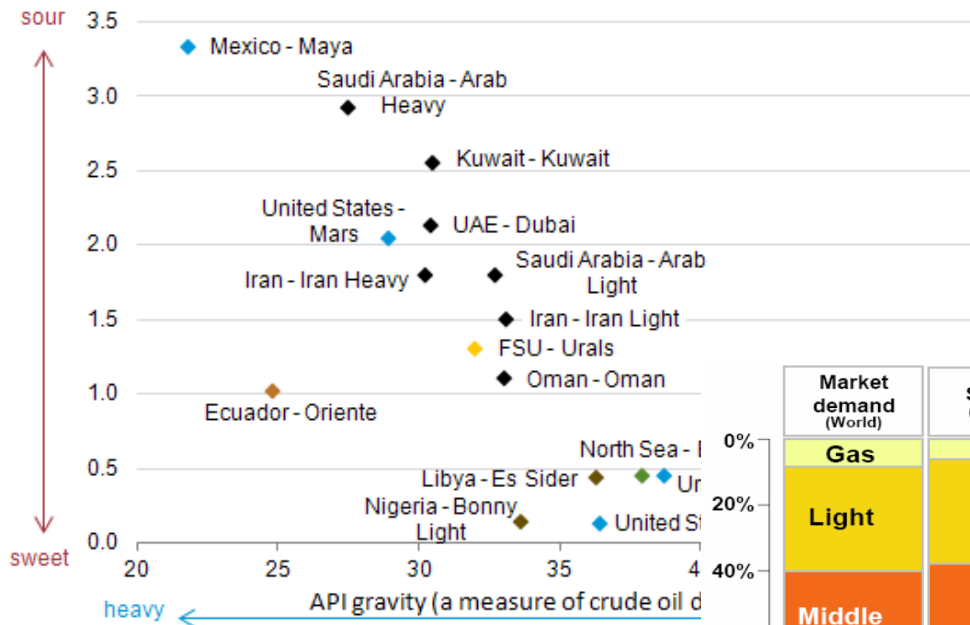


<sup>1</sup>[http://www.ufrgs.br/lapol/materias\\_primas/II\\_26.html](http://www.ufrgs.br/lapol/materias_primas/II_26.html)

<sup>2</sup><http://www.eia.gov/todayinenergy/detail.cfm?id=7110>

## ■ Petróleo

Density and sulfur content of selected crude oils  
sulfur content (percentage)



## ■ Gás natural

Composição química [% (v/v)]

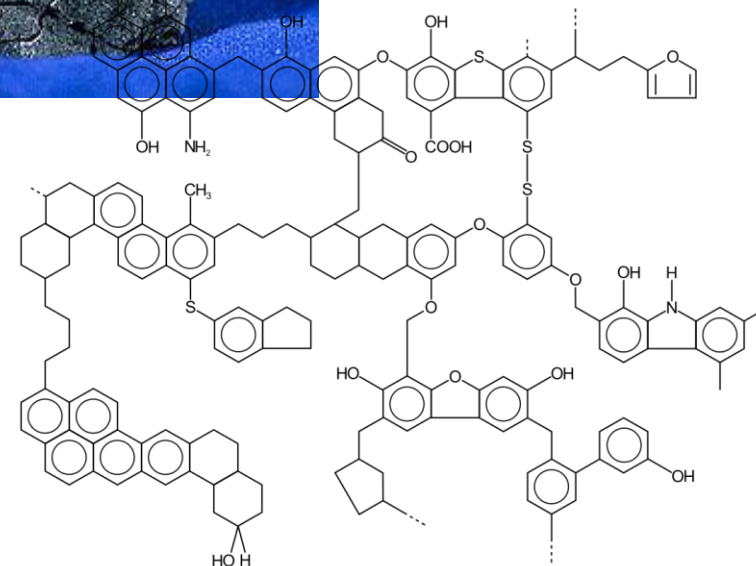
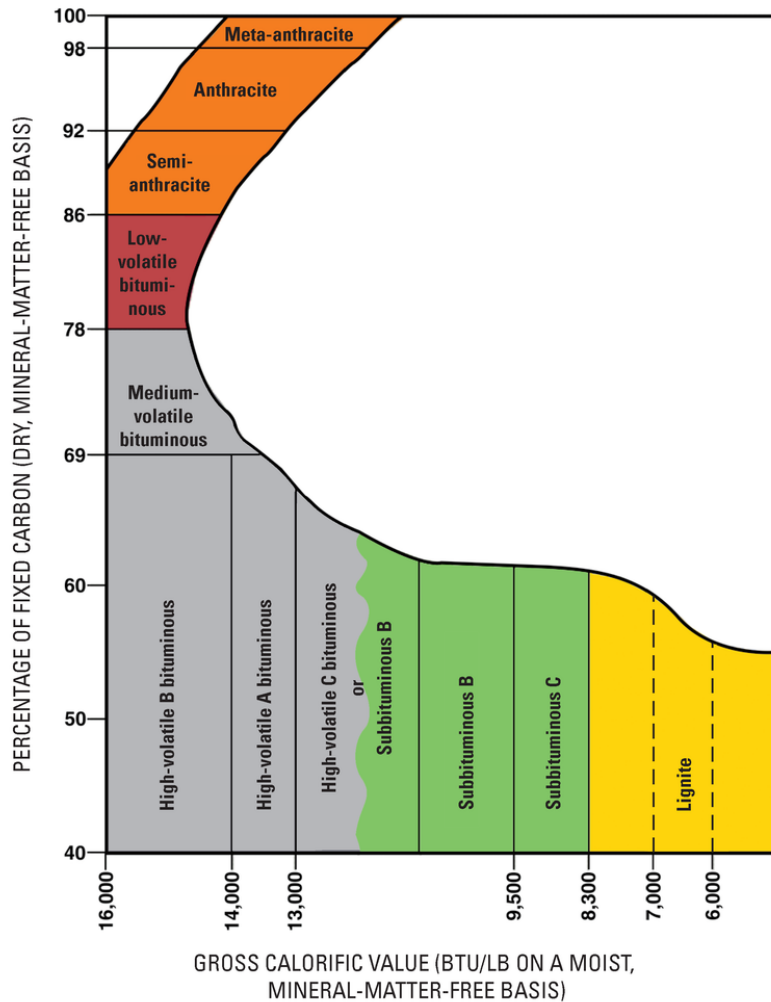
Component	Typical Analysis (mole %)	Range (mole %)
Methane	95.0	87.0 - 97.0
Ethane	3.2	1.5 - 7.0
Propane	0.2	0.1 - 1.5
iso - Butane	0.03	0.01 - 0.3
normal - Butane	0.03	0.01 - 0.3
iso - Pentane	0.01	trace - 0.04
normal - Pentane	0.01	trace - 0.04
Hexanes plus	0.01	trace - 0.06
Nitrogen	1.0	0.2 - 5.5
Carbon Dioxide	0.5	0.1 - 1.0
Oxygen	0.02	0.01 - 0.1
Hydrogen	trace	trace - 0.02
Specific Gravity	0.58	0.57 - 0.62
Gross Heating Value (MJ/m <sup>3</sup> ), dry basis *	38.0	36.0 - 40.2

## Carvão mineral

Composição química [% (m/m)]

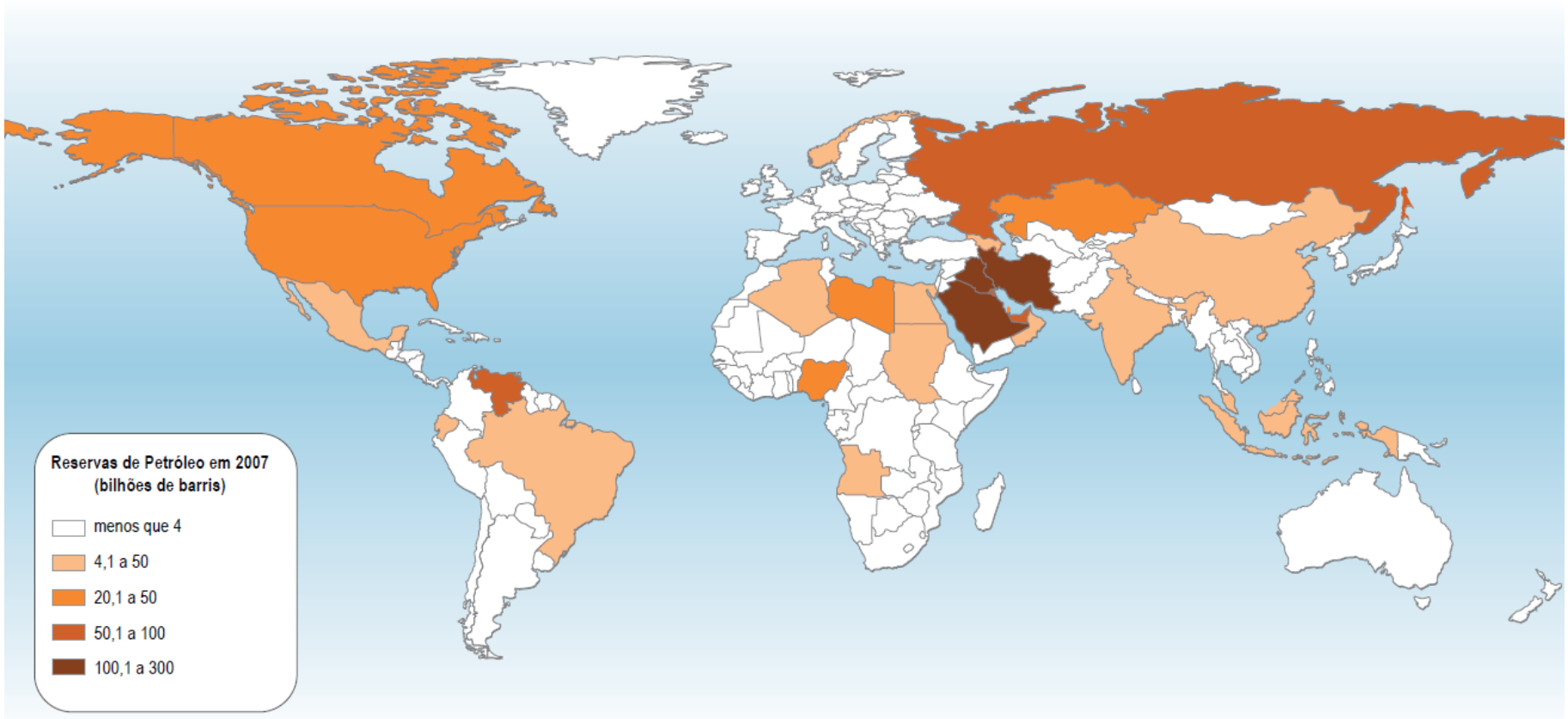
Types	Volatiles %	C %	H %	O %	S %	Heat content kJ/kg
Lignite (brown coal)	45–65	60–75	6.0–5.8	34-17	0.5-3	<28,470
Flame coal	40-45	75-82	6.0-5.8	>9.8	~1	<32,870
Gas flame coal	35-40	82-85	5.8-5.6	9.8-7.3	~1	<33,910
Gas coal	28-35	85-87.5	5.6-5.0	7.3-4.5	~1	<34,960
Fat coal	19-28	87.5-89.5	5.0-4.5	4.5-3.2	~1	<35,380
Forge coal	14-19	89.5-90.5	4.5-4.0	3.2-2.8	~1	<35,380
Nonbaking coal	10-14	90.5-91.5	4.0-3.75	2.8-3.5	~1	35,380
Anthracite	7-12	>91.5	<3.75	<2.5	~1	<35,300

## Carvão mineral





## ■ Petróleo

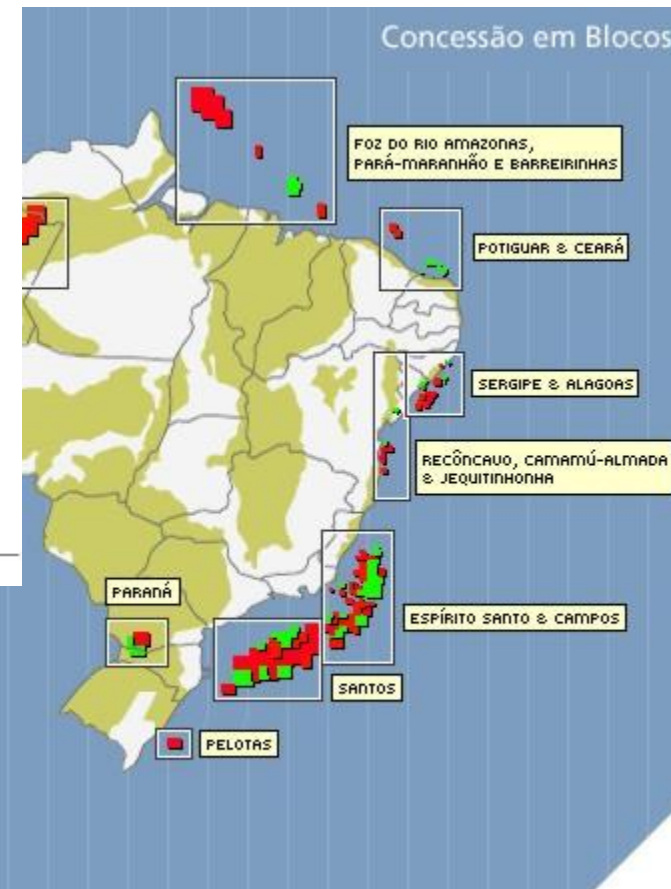
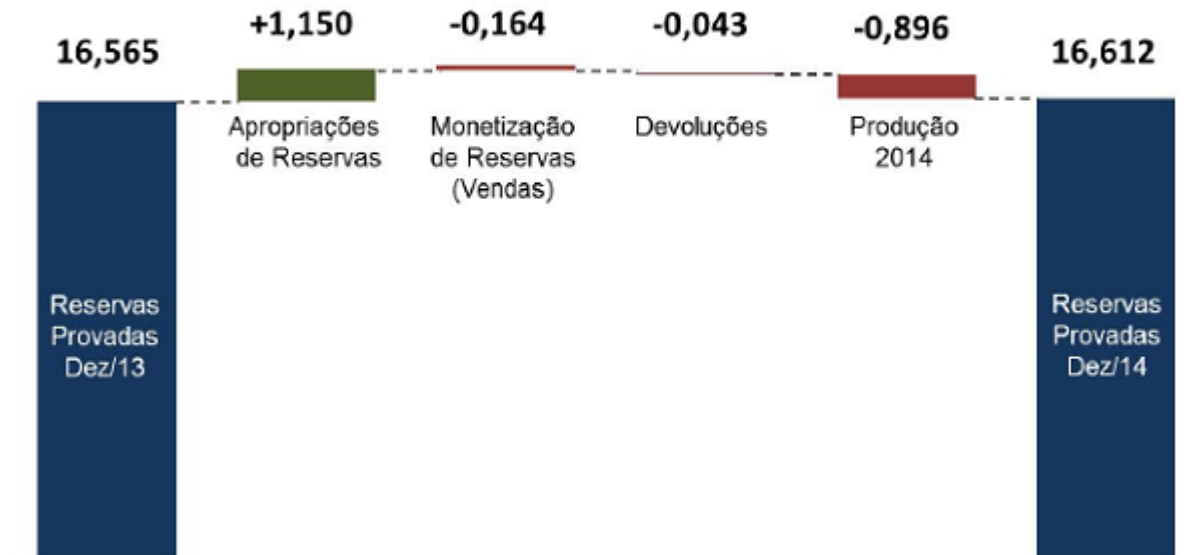


1238 bilhões de barris

17 bilhões de barris (Brasil)

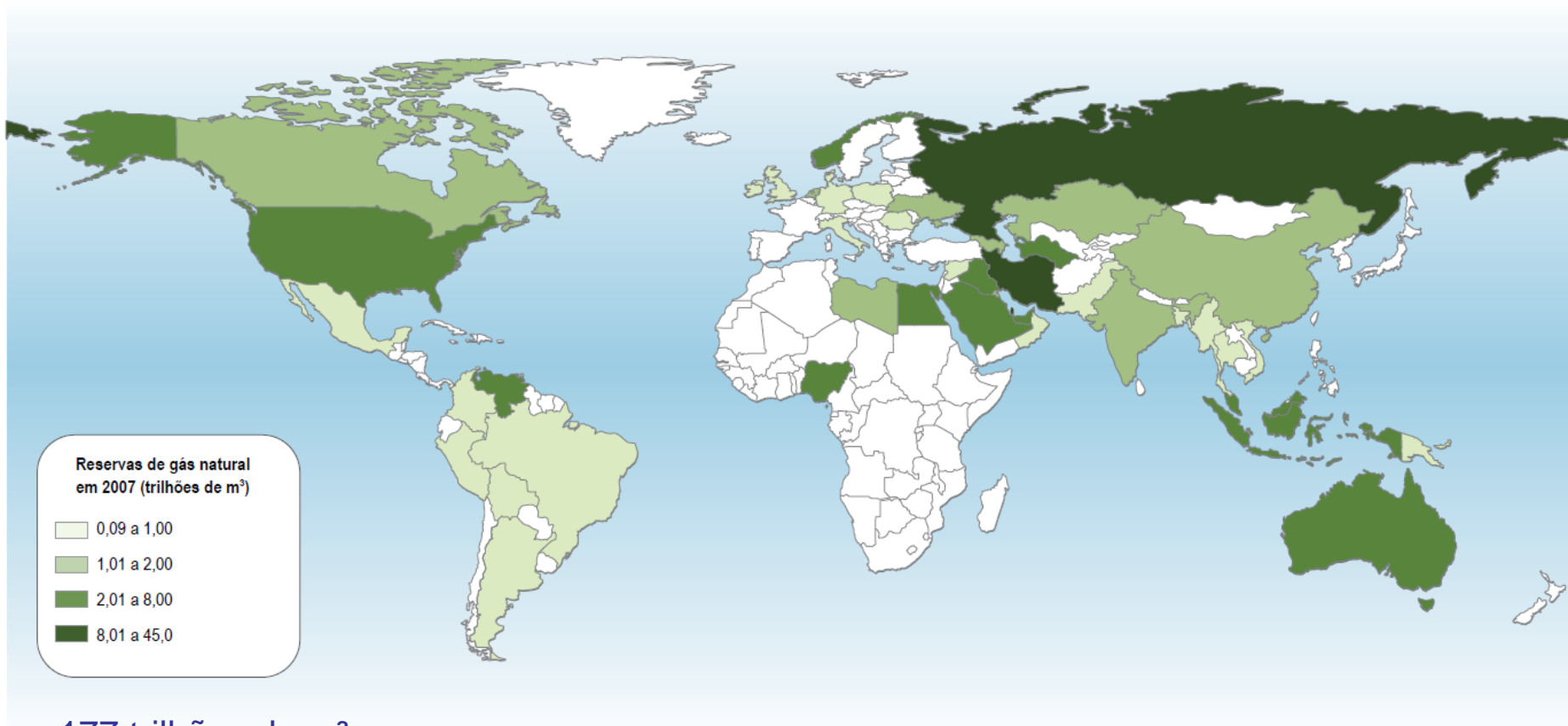
## ■ Petróleo

Gráfico 1 - Evolução das Reservas Provadas em 2014:  
Consolidado (critérios ANP/SPE, bilhões de boe)



# Reservas no mundo e no Brasil

- Gás natural (convencional)

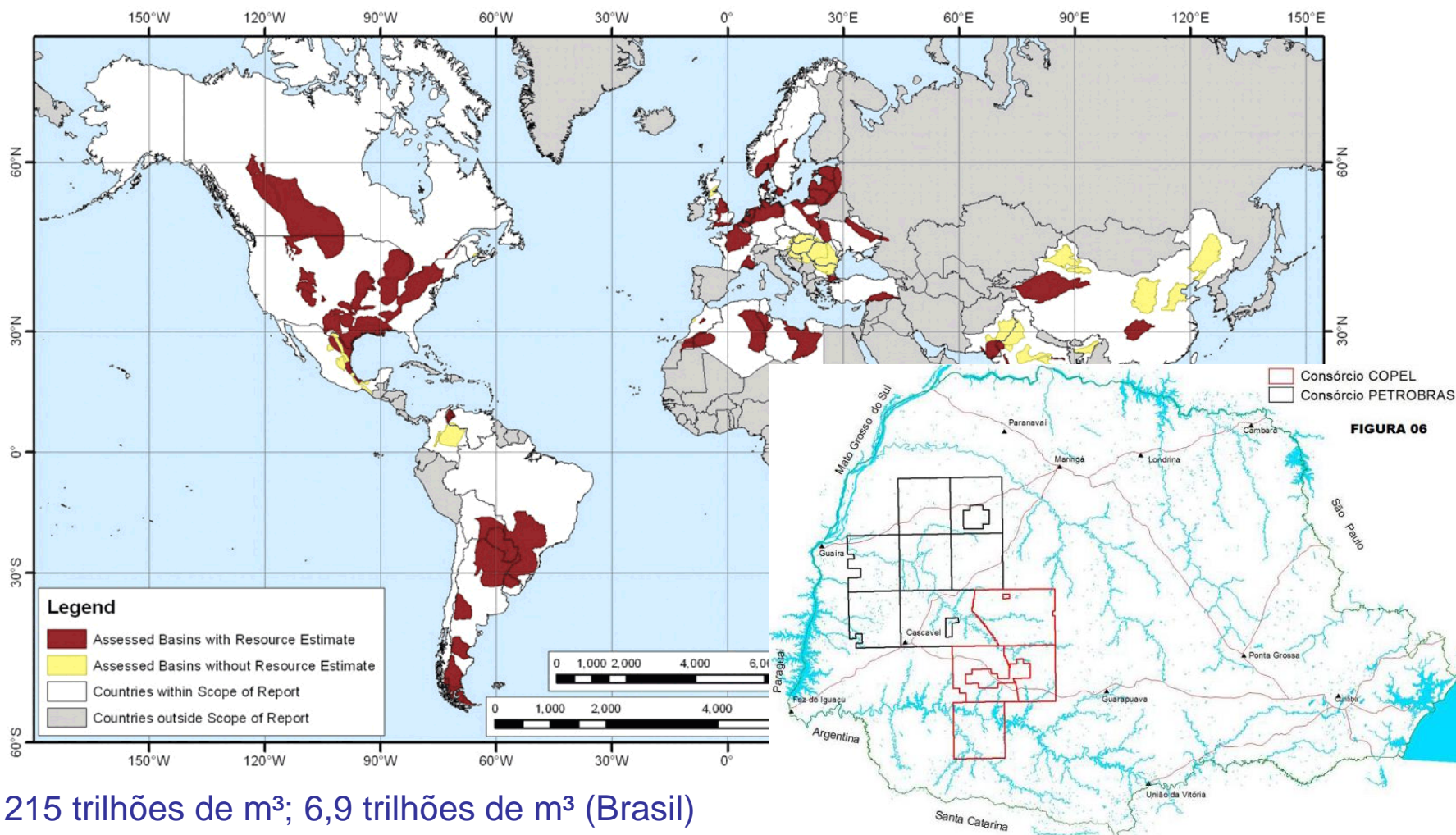


177 trilhões de m<sup>3</sup>

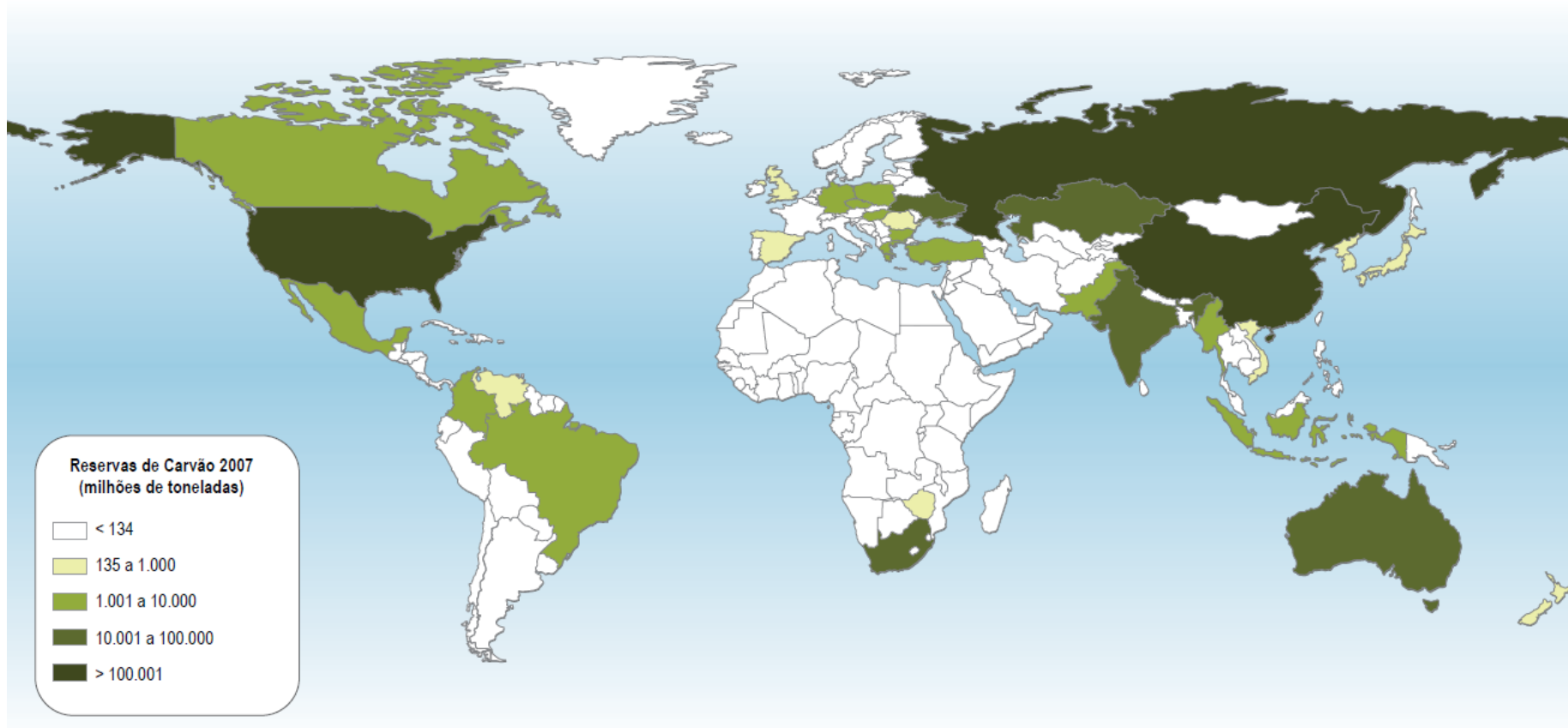
0,4 trilhões de m<sup>3</sup> (Brasil)

# Reservas no mundo e no Brasil

## ■ Gás natural (shale, gás de xisto)



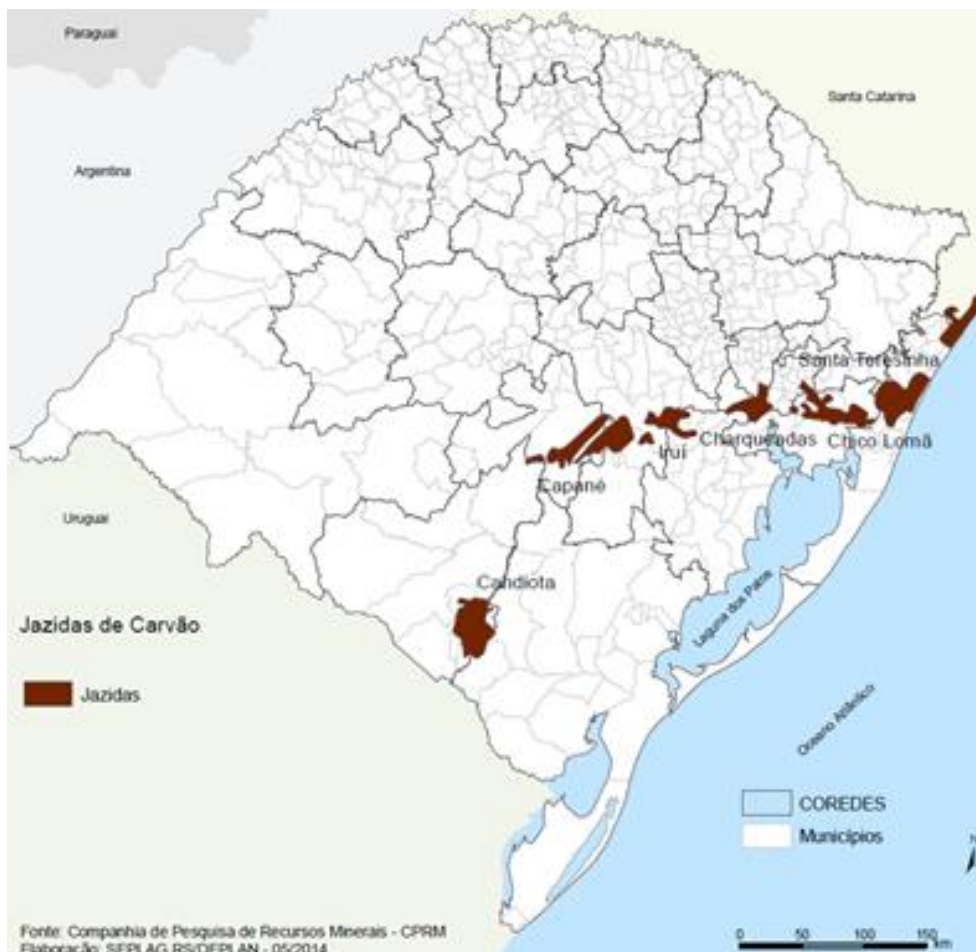
## Carvão mineral



847 bilhões de toneladas



## ■ Carvão mineral



Reservas RS

28,8 bilhões de toneladas

(89% das reservas nacionais)

# Modos de exploração

## ■ Petróleo

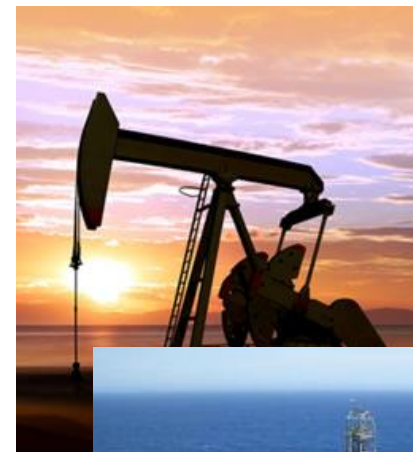
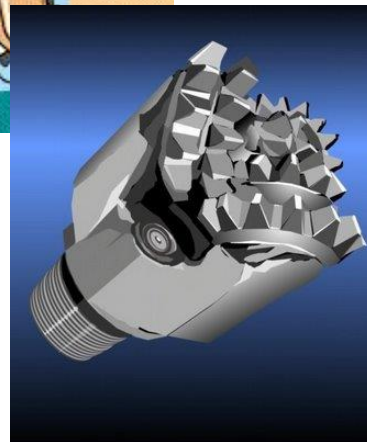
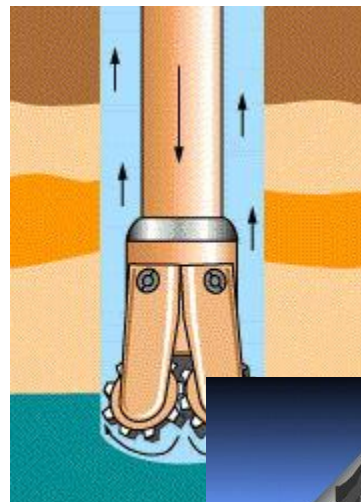
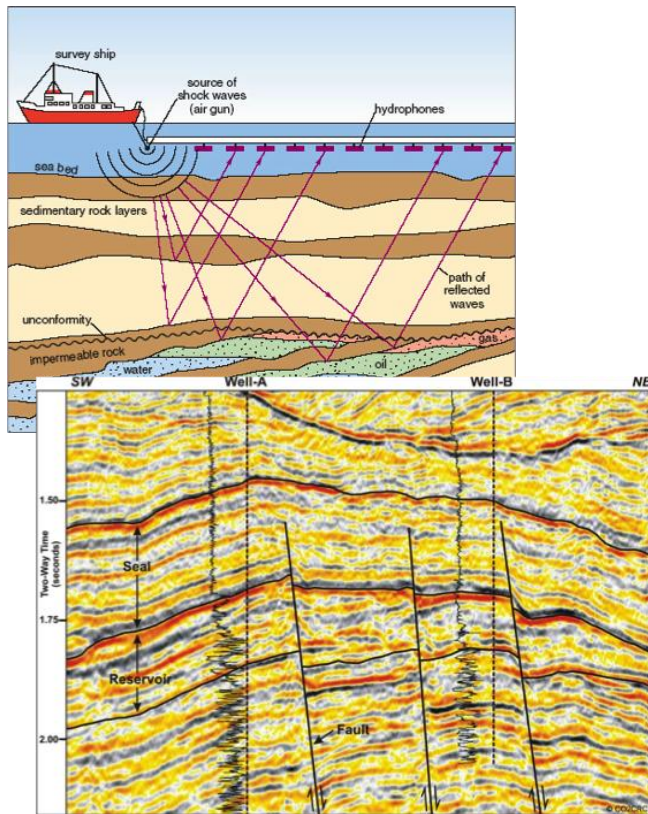
Prospecção



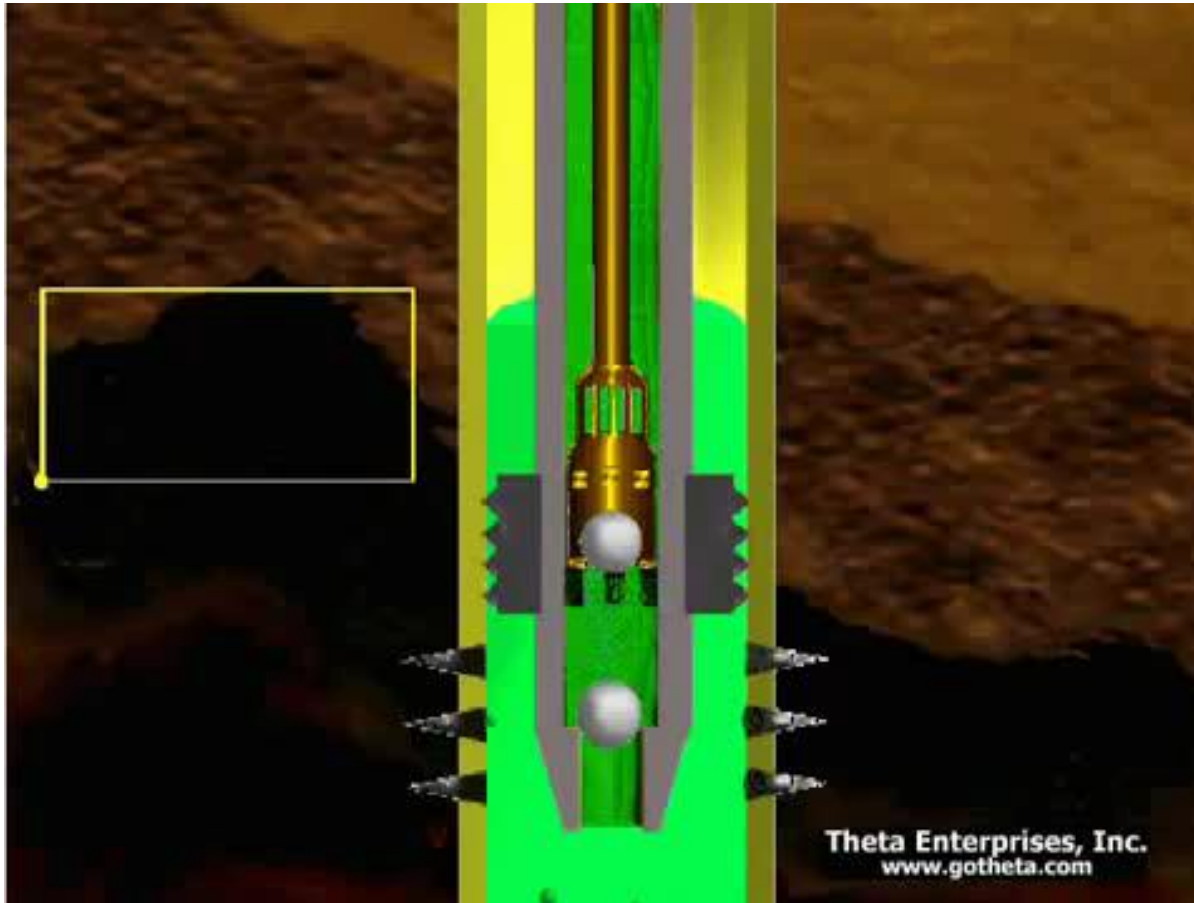
Perfuração



Extração



- Petróleo





## ■ Gás natural

Gás convencional



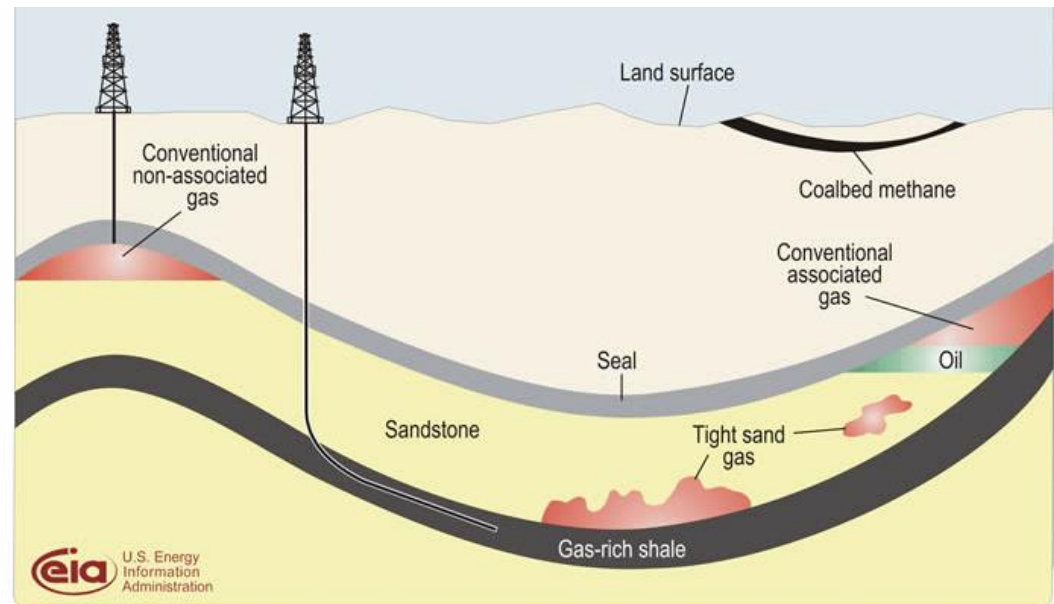
Gás associado

Gás não associado

Gás não convencional



Fracking



# Modos de exploração

## Carvão mineral

### Lavra do carvão

Céu aberto

Subterrânea



### Beneficiamento

Extração de materiais inertes

Secagem

- Carvão mineral

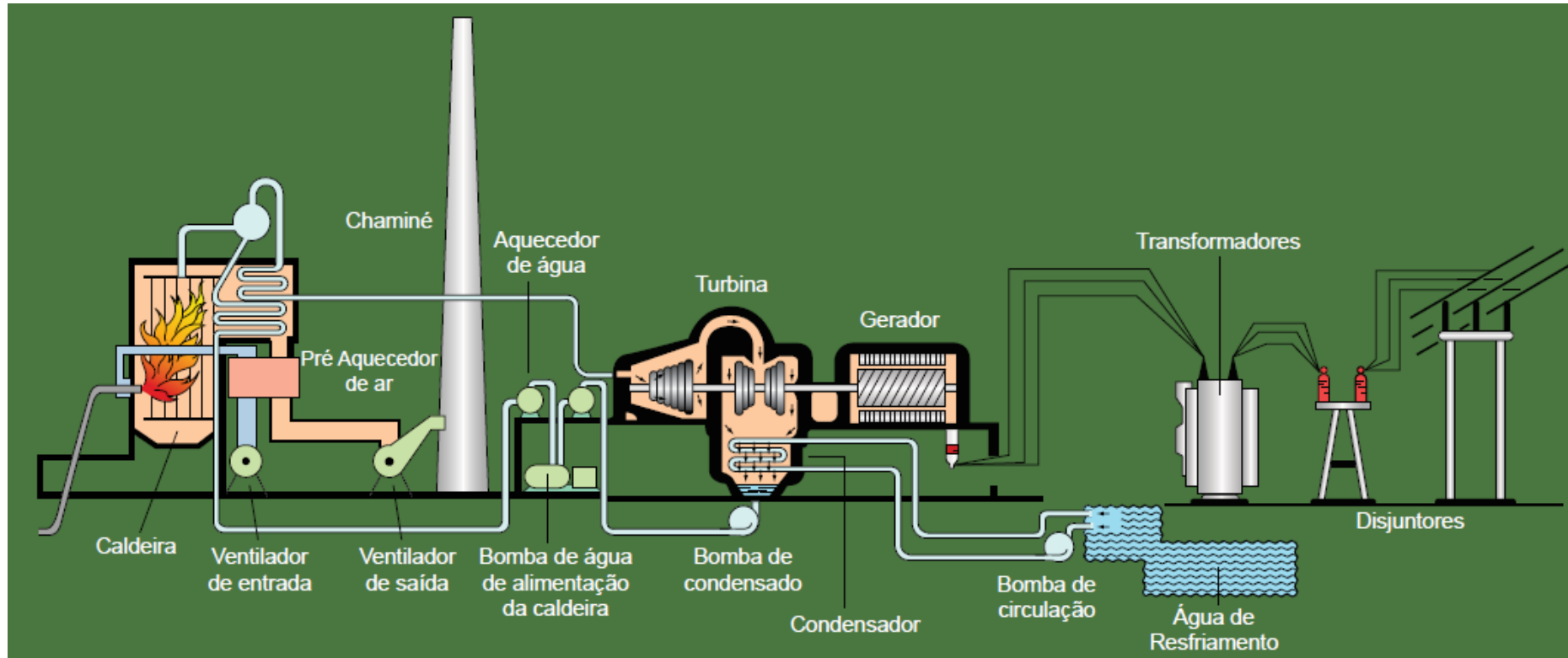


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- Diagrama de Sankey (International Energy Agency)
  - Avaliar consumo final (transporte, geração termelétrica, outros usos);
  - [http://www.iea.org/sankey/#?c=IEA Total&s=Balance](http://www.iea.org/sankey/#?c=IEA%20Total&s=Balance)



## ■ Petróleo



# Uso final

- Petróleo



SUAPE: 381 MW; FC=0,70



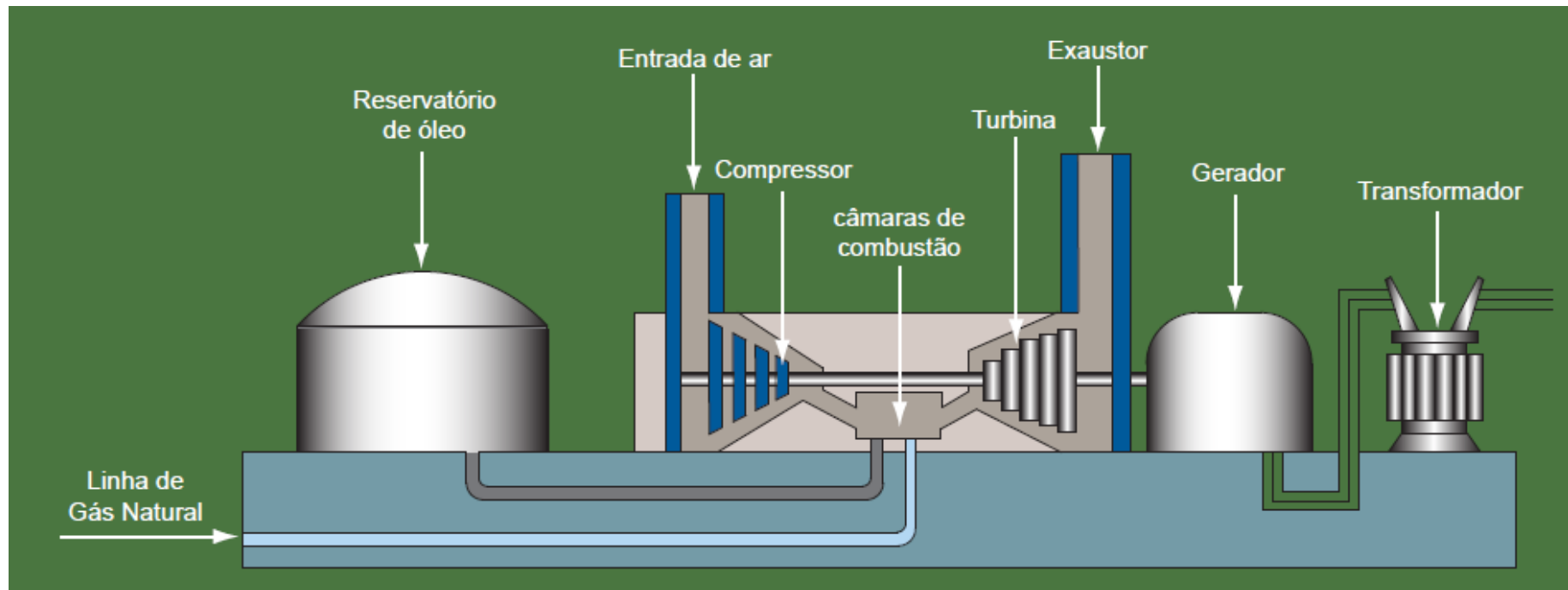
Borborema Energética: 169 MW; FC=0,76

- Petróleo

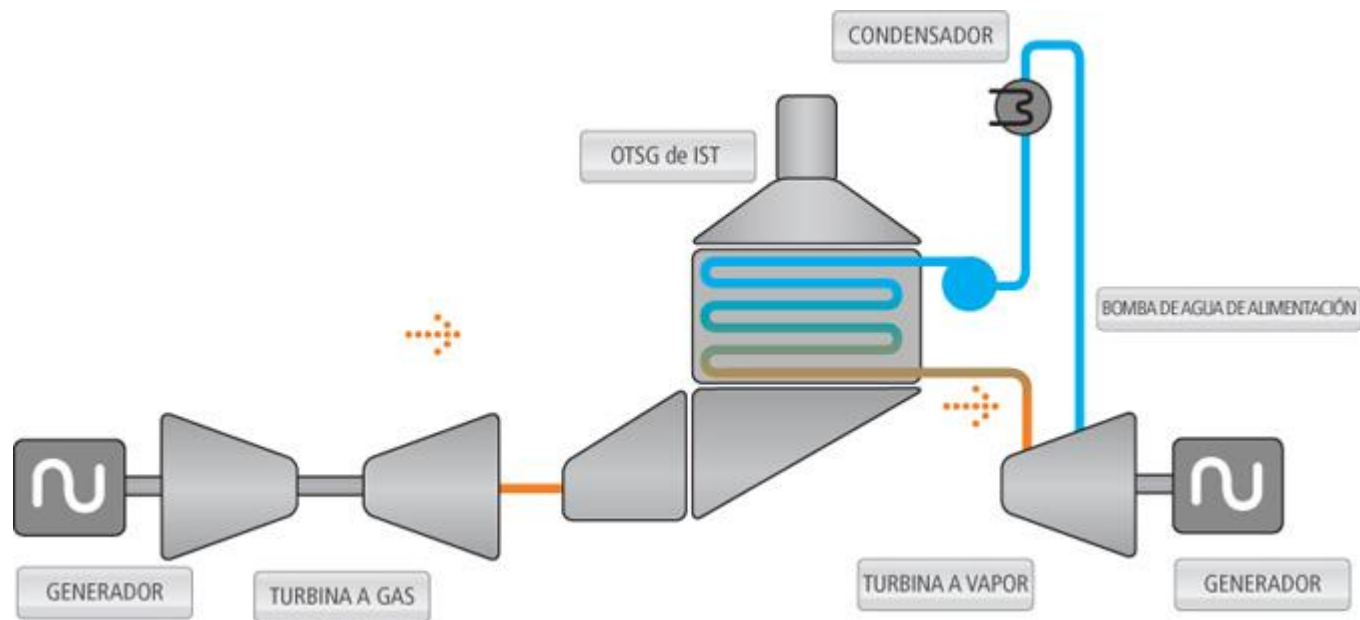




- Gás natural



- Gás natural

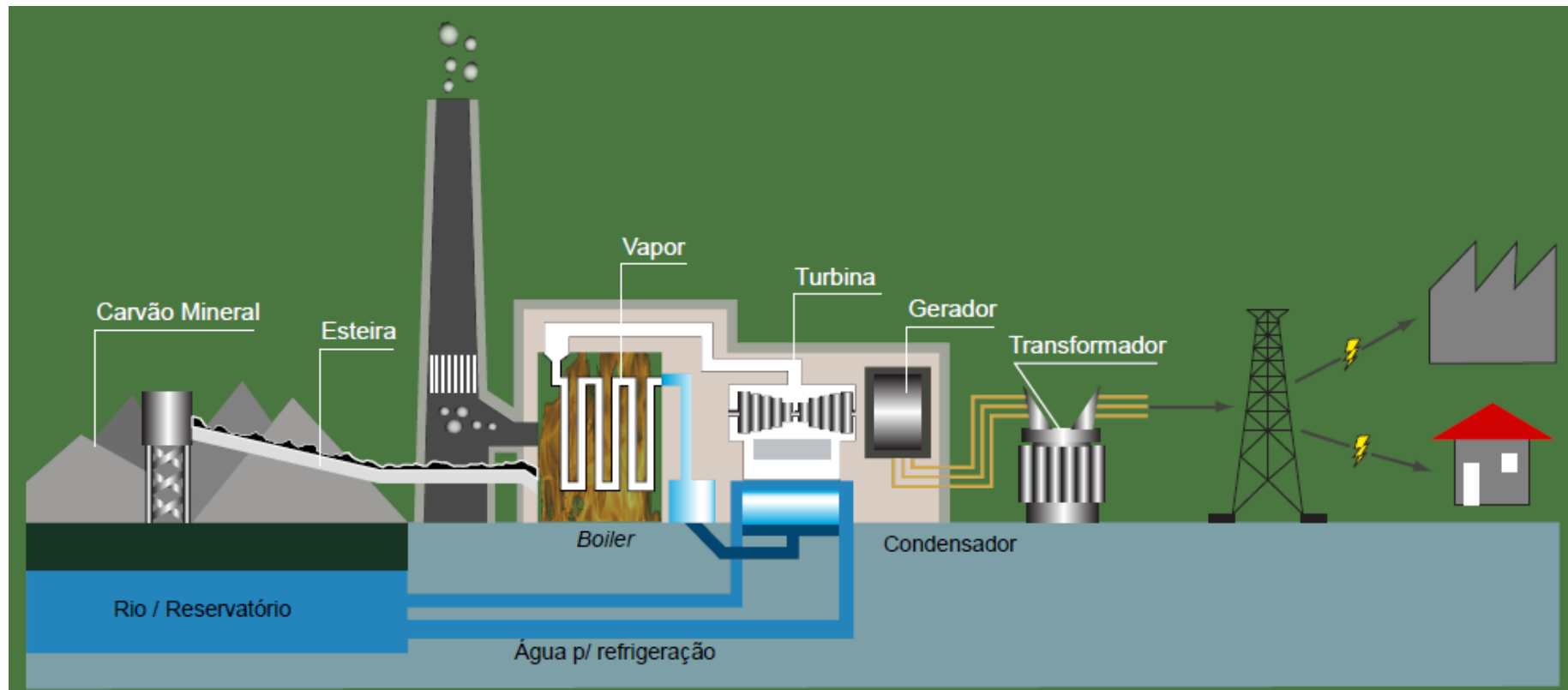


- Gás natural



TERMOPE: 530 MW; FC=0,81

- Carvão mineral



- Carvão mineral



Jorge Lacerda, Unidade C, Santa Catarina

363 MW

170 bar; 538 C



- Carvão mineral



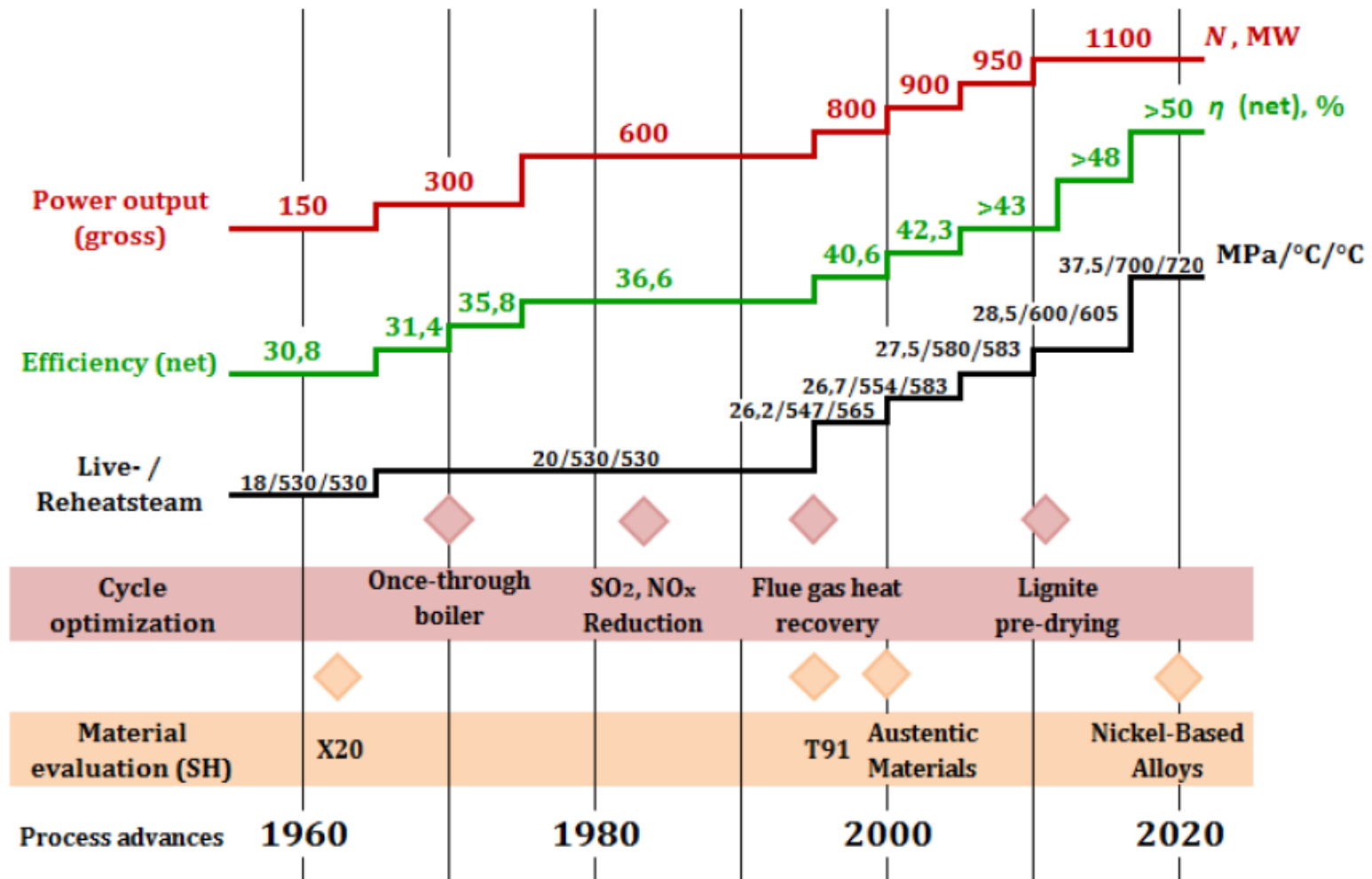
Boa 2 e 3; Nordrhein-Westfalen, Alemanha

1.060 MW + 1.060 MW; 280 bar / 600 C



# Uso final

## Carvão mineral

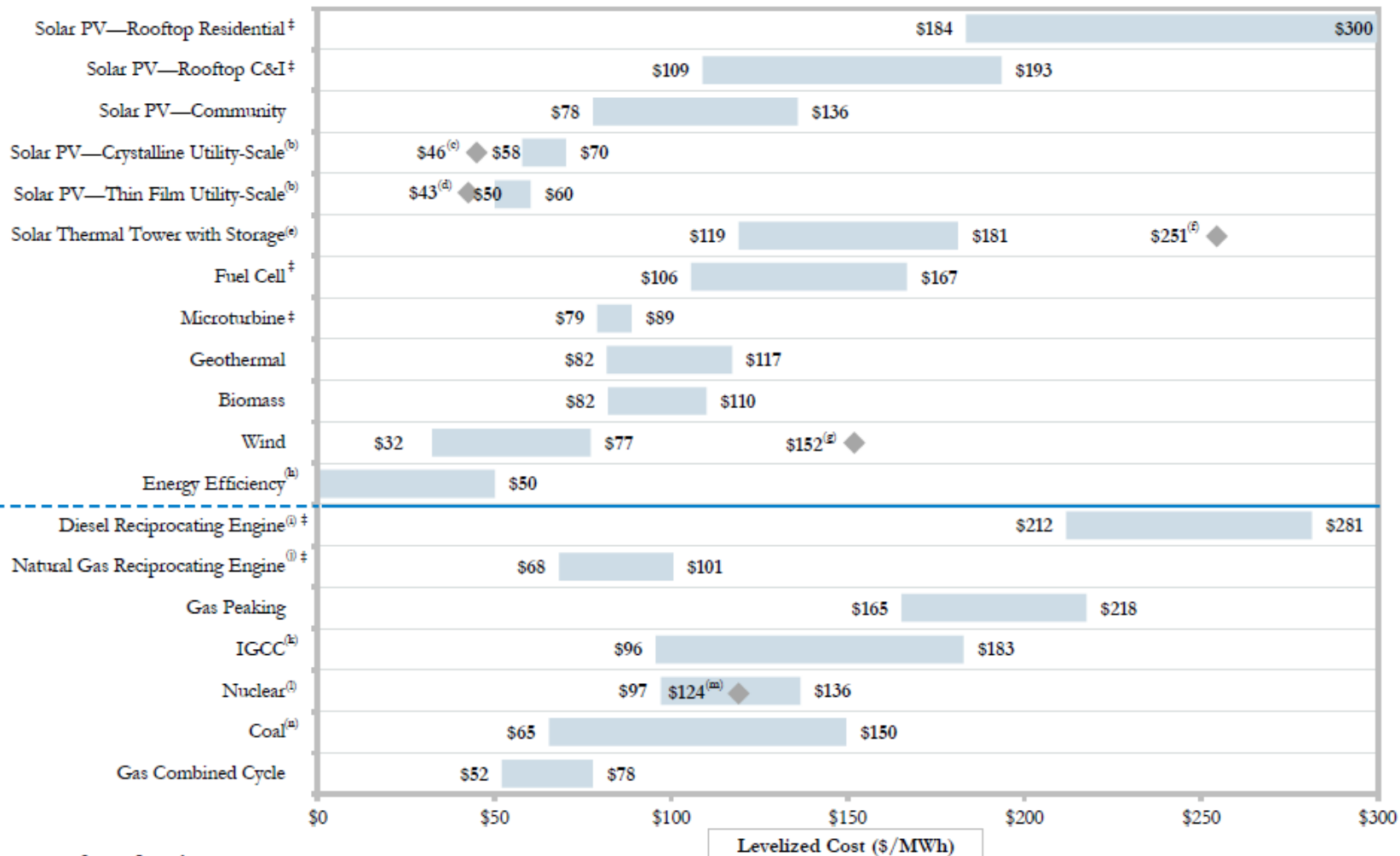




## ■ Custo de geração nos USA, LCOE [US\$/MWh]

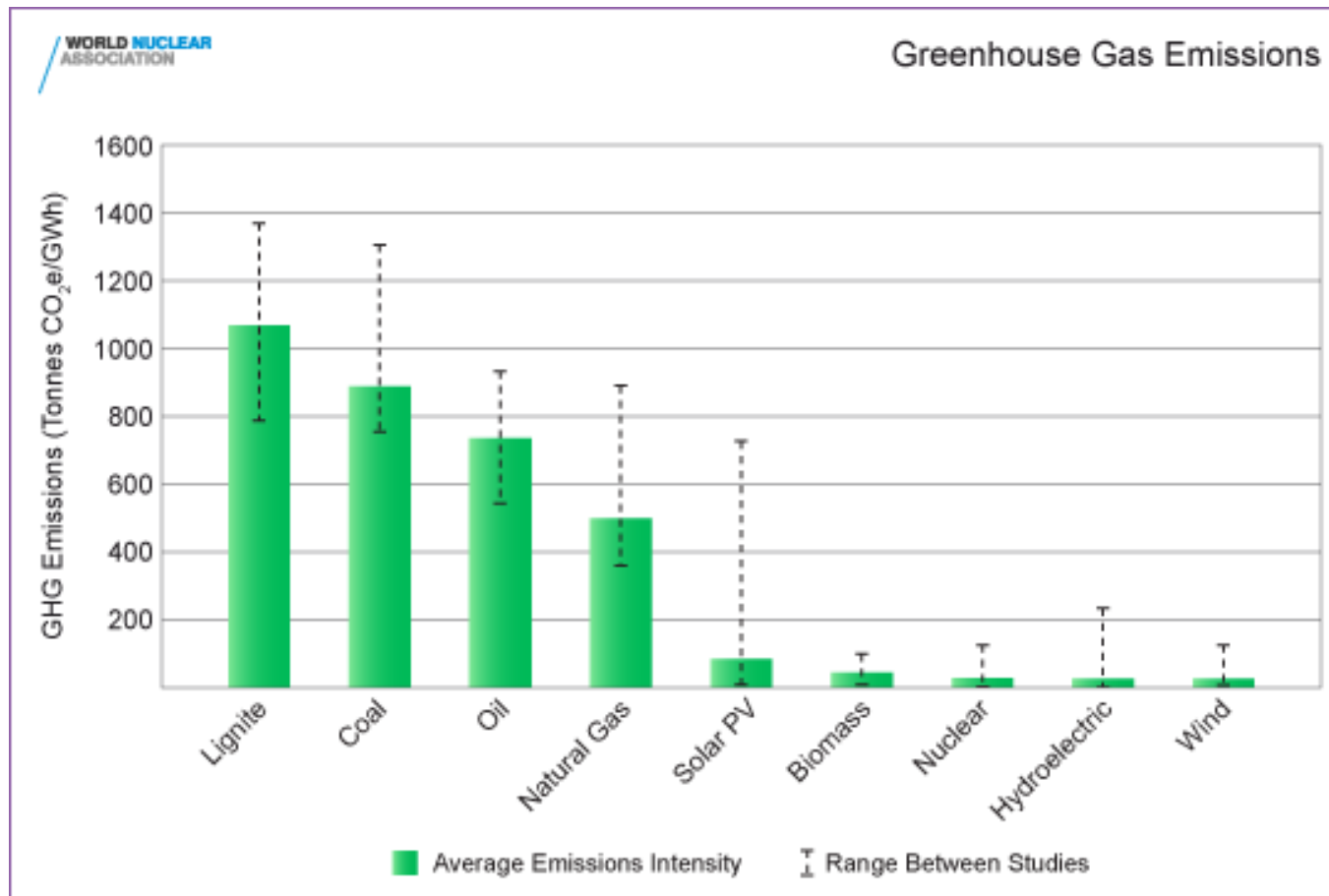
ALTERNATIVE ENERGY<sup>(\*)</sup>

CONVENTIONAL



Source: Lazard estimates.

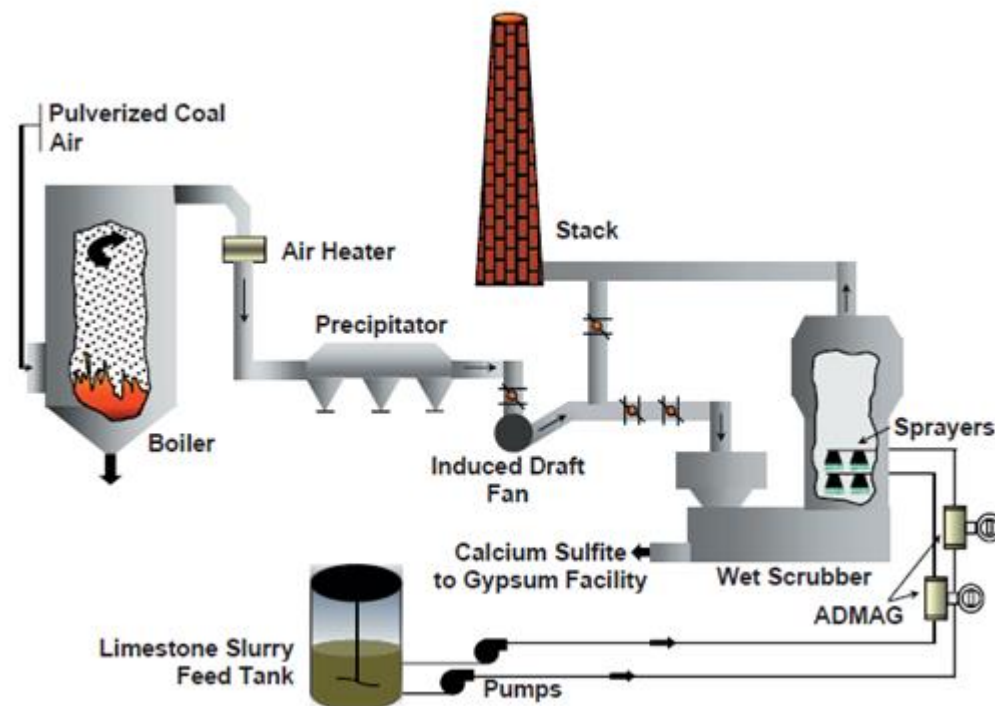
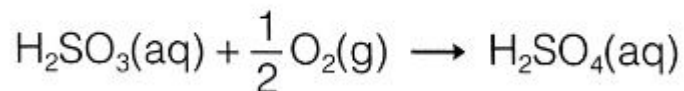
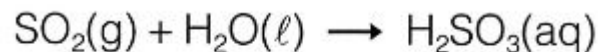
- Emissão de gases do efeito estufa



## ■ Emissões de SO<sub>x</sub>

- Queimar combustíveis com menor teor de S;
- Tratar gases de combustão

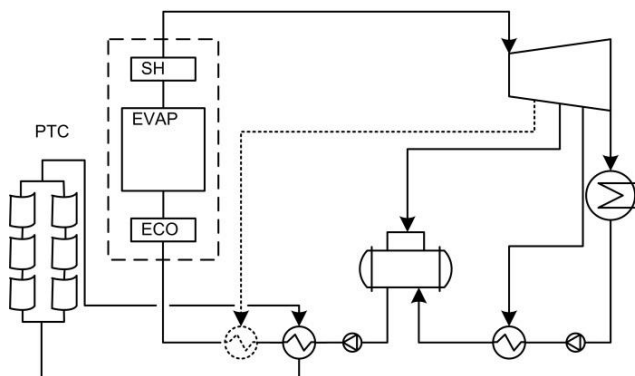
Formação de chuva ácida



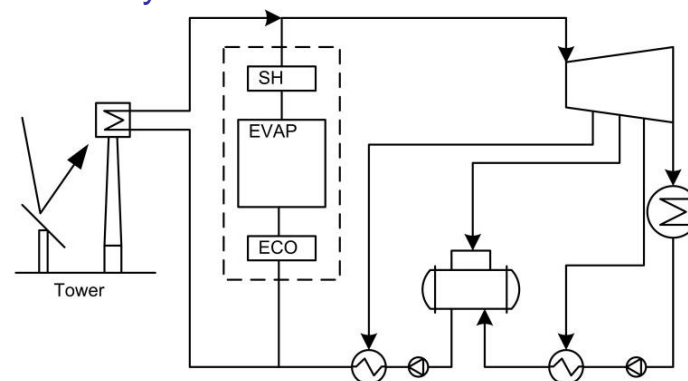
- Emissões de NOx
  - NOx combustível
  - NOx térmico ( $>1400$  C)
- Desafios
  - Aumentar a eficiência dos sistemas de geração termelétrica
  - Desenvolvimento de combustíveis com baixo teor de S
  - Encontrar substitutos para os fósseis

## ■ Geração Solar+Fossil

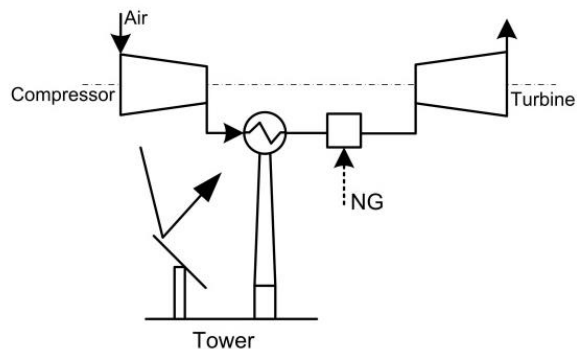
SAFWH: Solar-Aided Feedwater Heating



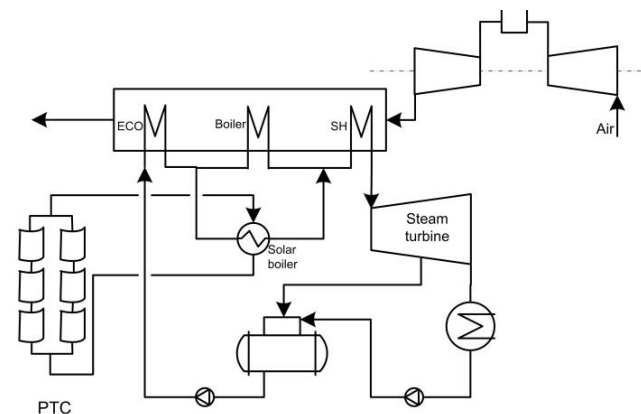
HSG: Hybridized Steam Generators



SGT: Solar-Gas Turbines



ISCC: Integrated Solar Combined Cycles



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