WG10 Summary:

Green Accelerators

Co-convenors:

Hitoshi Hayano (KEK)	Belgrade, LCWS2014
Steve Peggs (BNL/ESS)	Beijing, HF2014

5 presentations

Beijing:

"Energy consumption and savings potential of CLIC."
Philippe Lebrun (CERN)

"A green CEPC using the power of nuclear waste."
Zhenchao Liu, Jie Gao (IHEP)

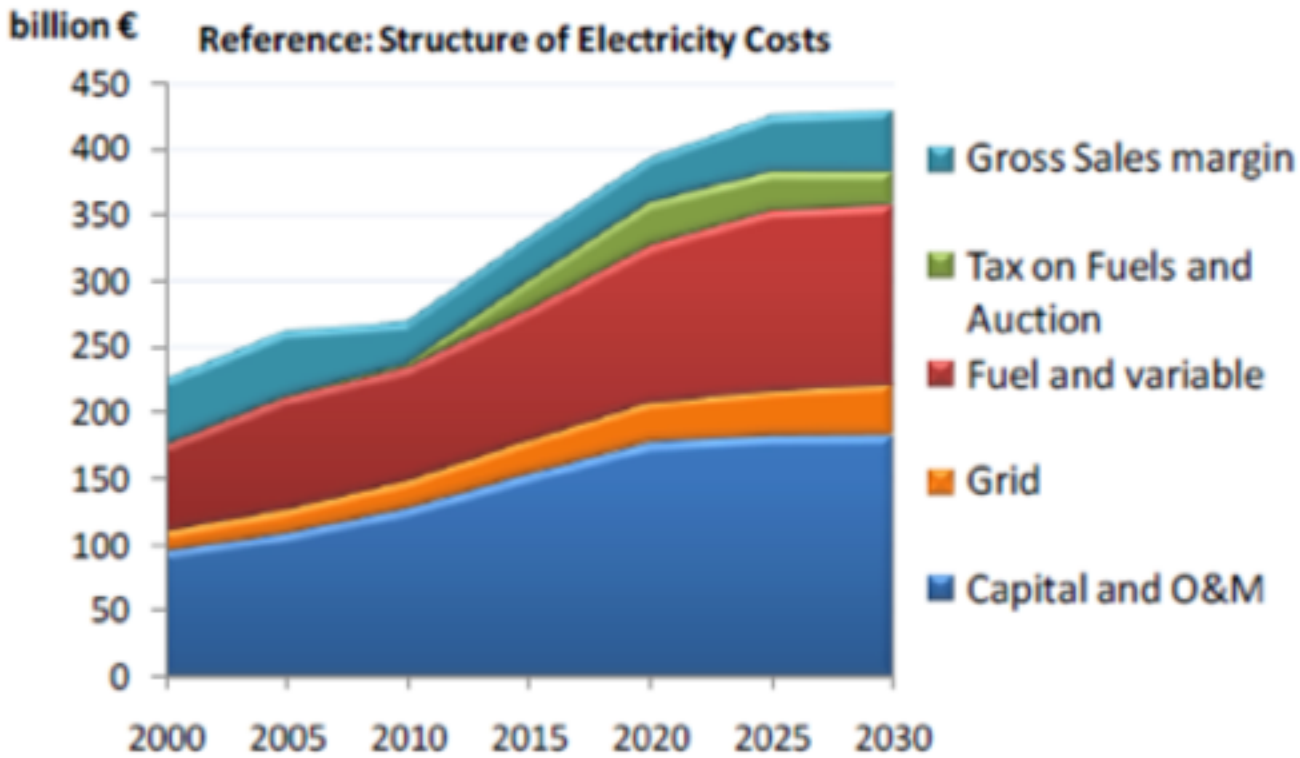
"Greening for bosons."
Thomas Parker (ESS)

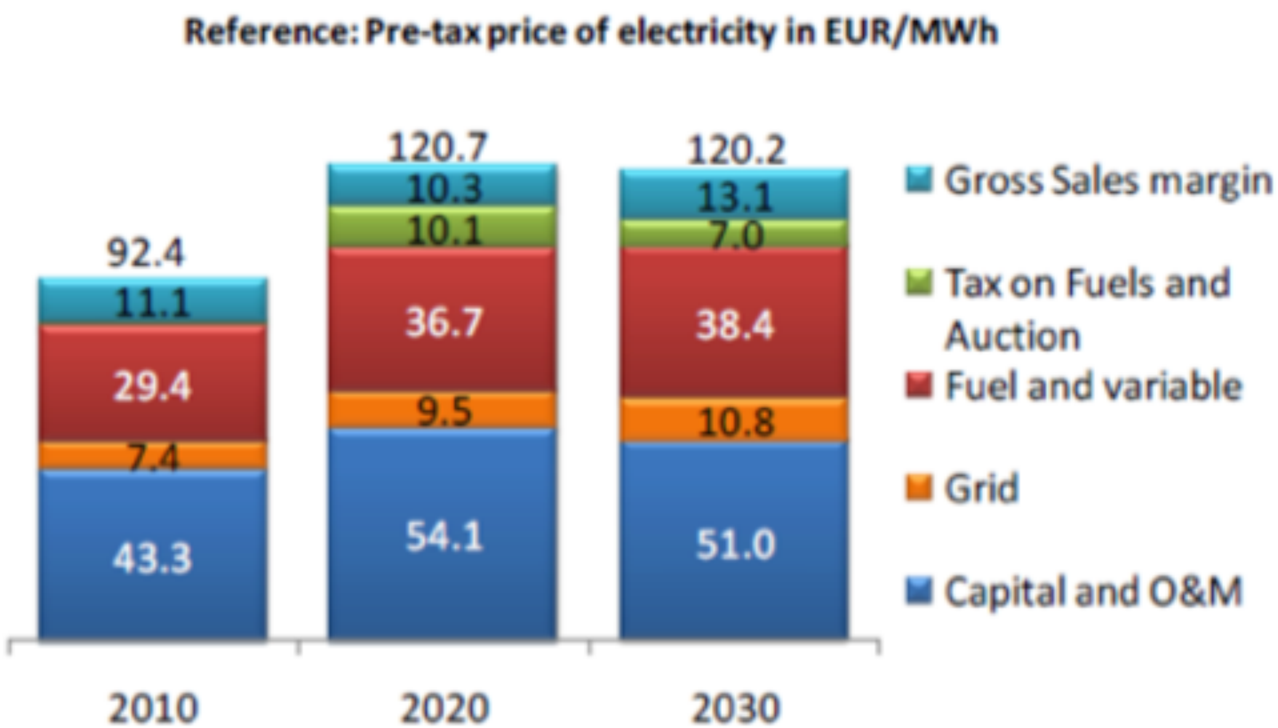
Belgrade:

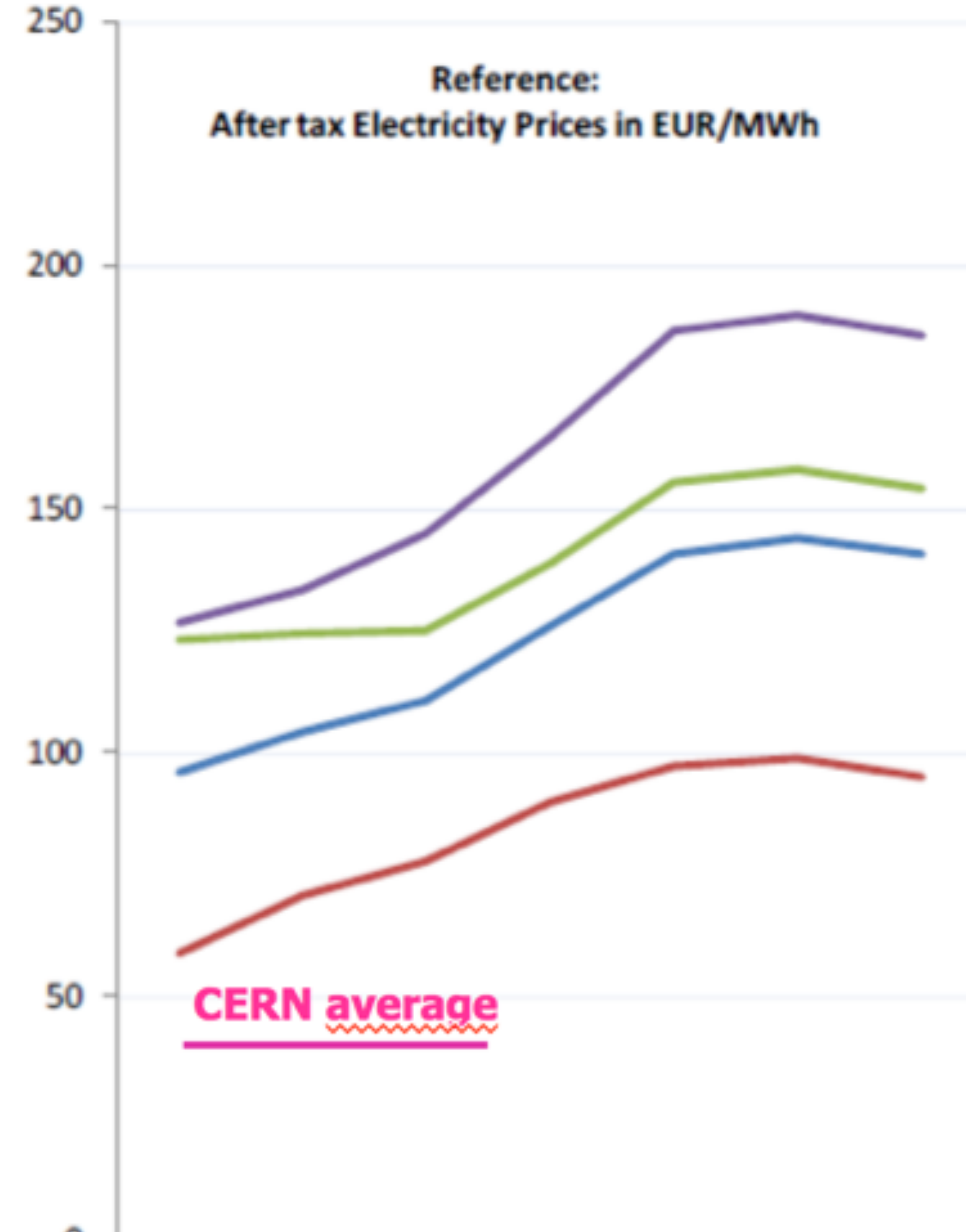
"HEP future: to be green, or not to be?"
Denis Perret-Gallix (CERN)

"Current status of Green-ILC activities in Japan."
Takayuki Saeki (KEK)

Lebrun: electricity price projections

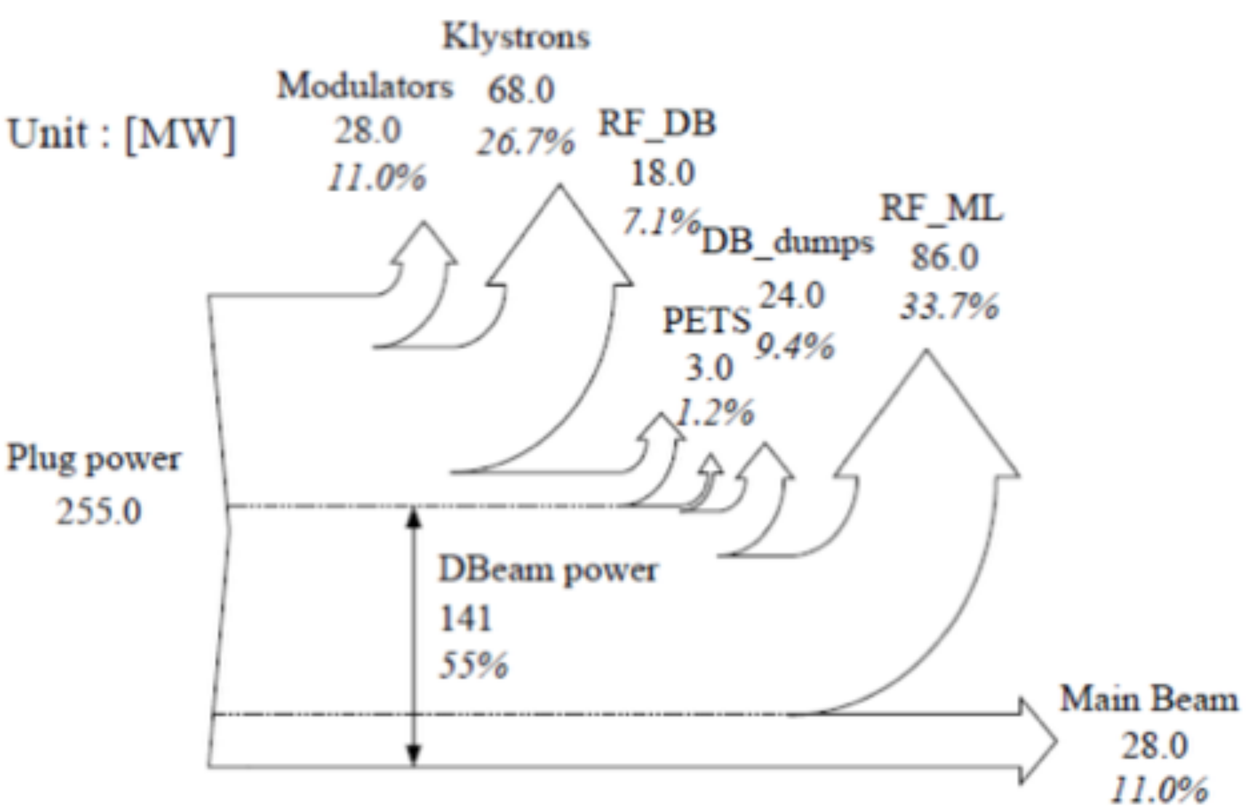




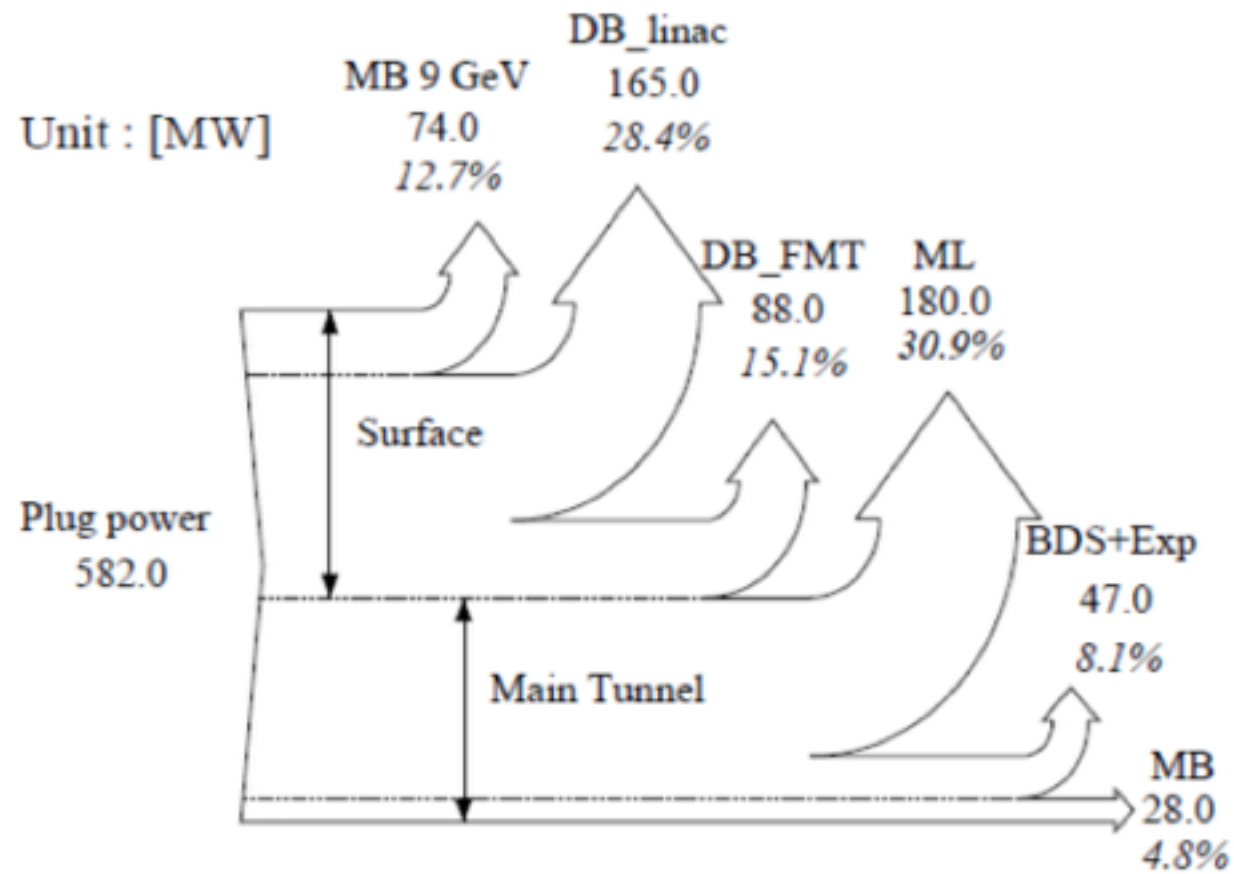


	2000	2005	2010	2015	2020	2025	2030
Average	96	104	110	126	141	144	141
Industry	59	71	78	90	97	99	95
Services	123	124	125	139	155	158	154
Households	127	133	145	165	186	190	186

CLIC power flow

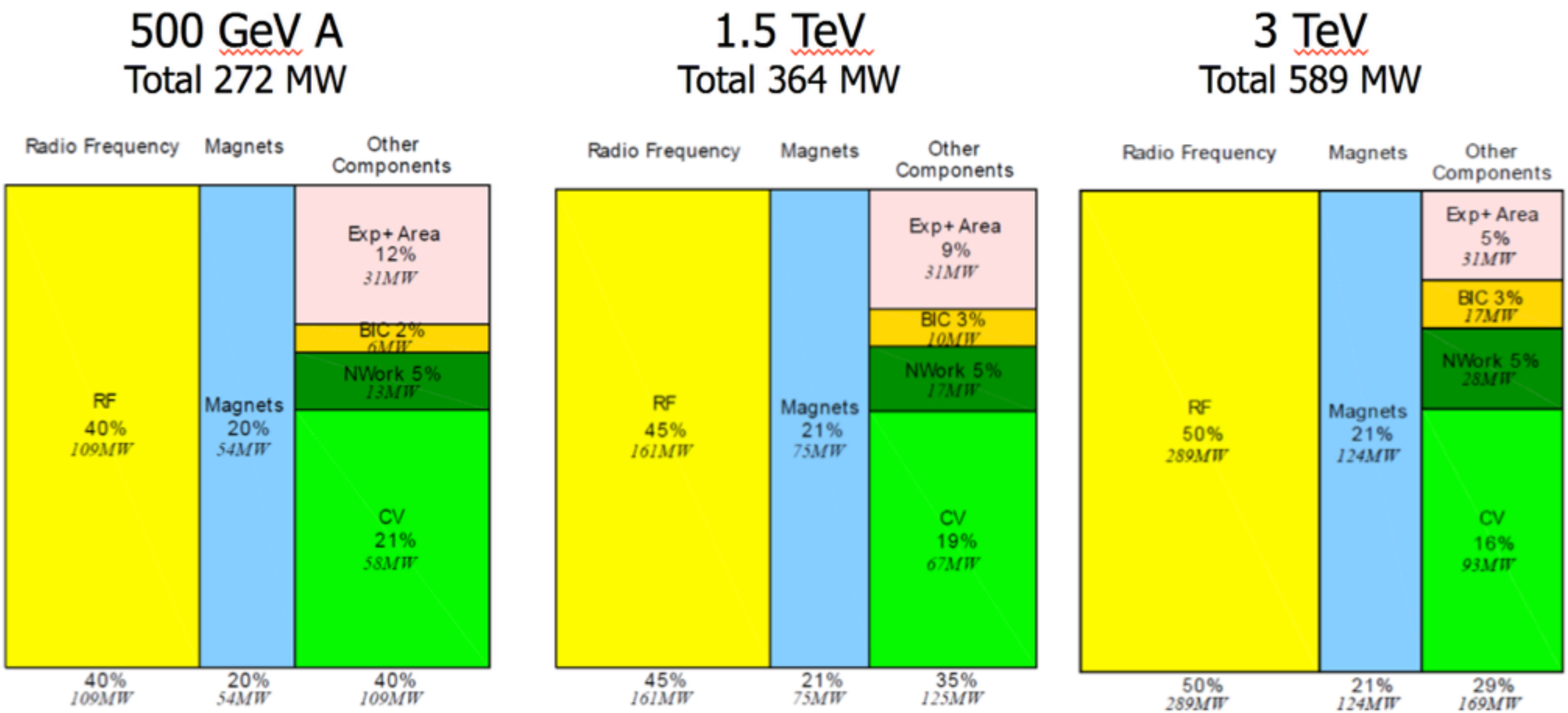


Power flow for the main RF system of CLIC at 3 TeV



Overall power flow for CLIC at 3 TeV

Consumption by technical system



CV: cooling & ventilation, NW: electrical network losses, BIC: beam instrumentation & control

The four pillars of energy economy

Lebrun: Conclusions

- Power consumption of CLIC and other large accelerator projects at the energy frontier has become a major issue in their technical feasibility, economic affordability and social acceptance
- Power and energy savings are therefore essential aspects of the study of such machines from the conceptual design phase
- Paths towards this goal must combine sobriety, efficiency, optimal energy management and waste heat recovery and valorisation
- Exergy content of CLIC waste heat remains low at acceptable recovery temperatures
  - Conversion to mechanical work is inefficient
  - Use for heating/cooling may be economical, provided one finds concomitant needs

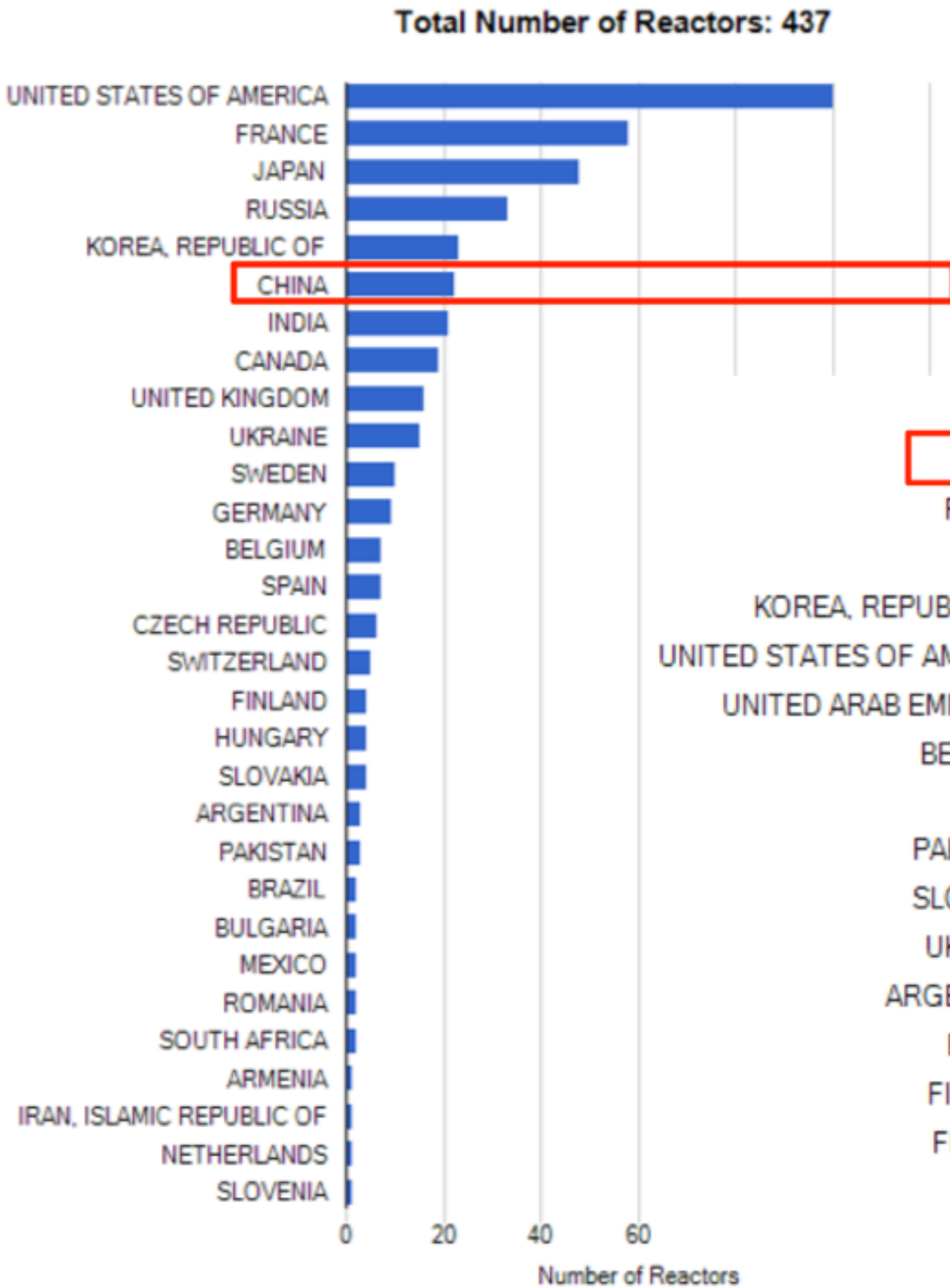
Liu: CEPC power consumption

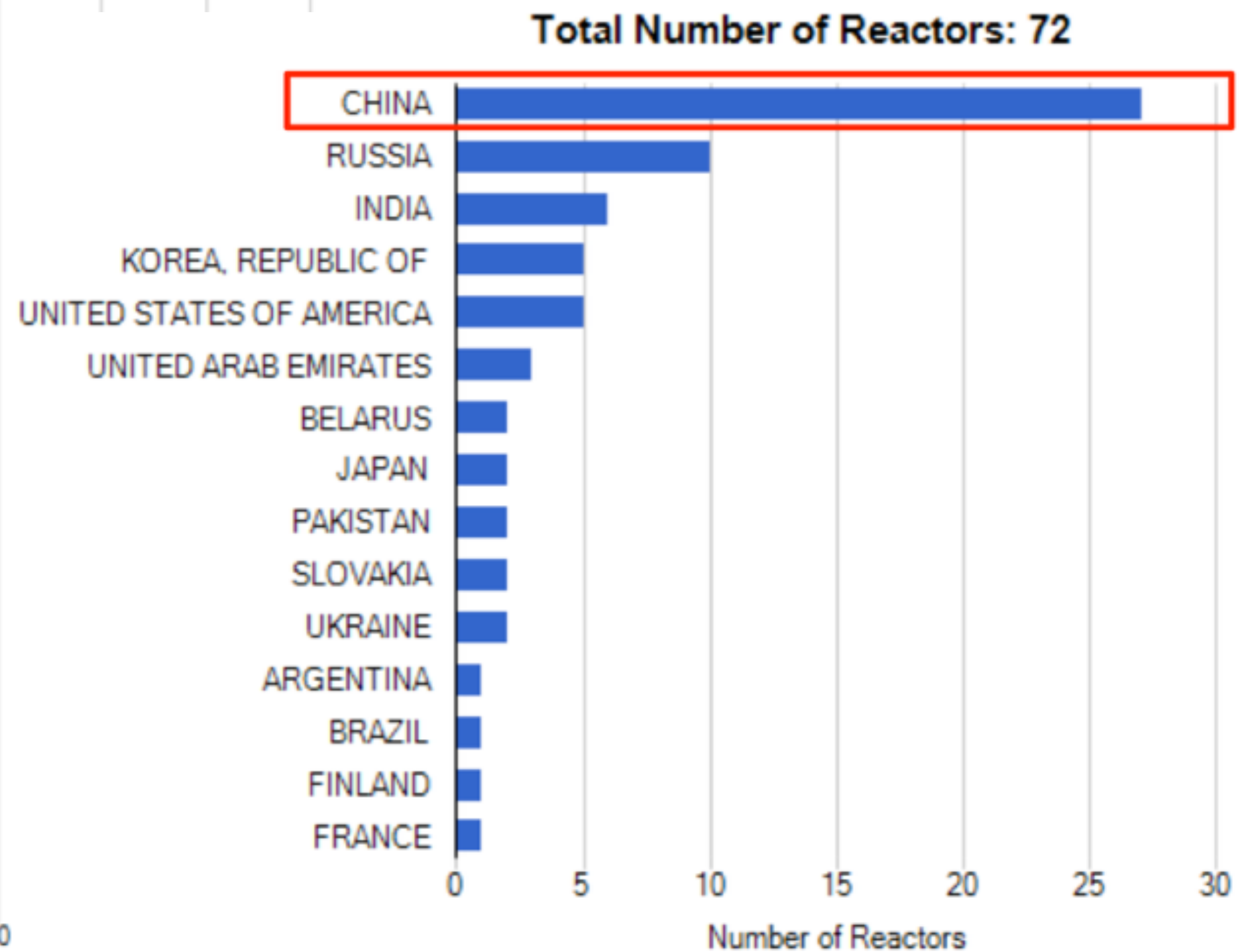
- Synchrotron radiation:
  - One beam 50MW, two beams 100MW
- Total: ~300MW
  - including power source, cryogenic system (LHe,LN_2) and so on.
- Compare with LHC and ILC
  - CERN at peak 180MW, ~140MW average (24/7), one year 1.2TWh, 50-60M€/year(40-50 €/MWh)
  - ILC: 300MW for 500GeV and 500MW for 1TeV, 160M €/year for 500GeV (135 €/MWh)

2013 investments in renewable energy

- China 56 billion U.S. dollar, for the first time more than Europe
- Europe 48 billion U.S. dollar
- USA 36 billion U.S. dollar
- India 6 billion U.S. dollar
- Brazil 3 billion U.S. dollar

Reactors in operation (Left) & construction (Right)

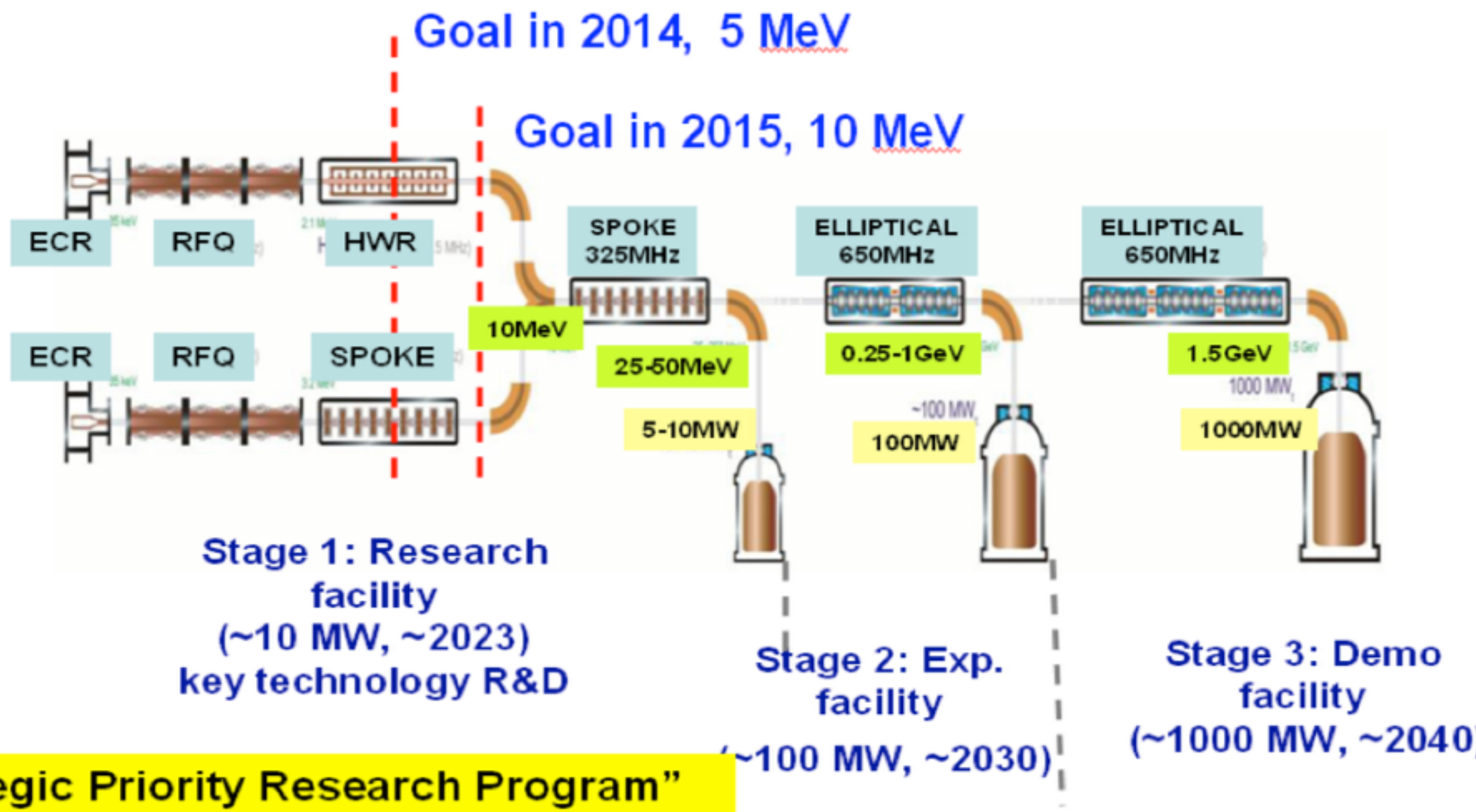




ADS program

- Nuclear waste is a bottle neck for nuclear power development in China
- ADS has been recognized as a good option for nuclear waste transmutation.
- ADS has been supported by CAS as a long-term program.
- Many accelerator technologies have been developed by the ADS R&D, such as SC technology, RF power source, SC magnet…
- ADS can provide electric power to the society as a nuclear plant. The fuel can be nuclear waste or thorium (Th-232) since it is three times as abundant in the earth's crust as uranium.

China-ADS roadmap



"Strategic Priority Research Program" of the Chinese Academy of Sciences

Liu: conclusions

- CEPC is a large machine and need huge power of 300MW, ~ 2 times of LHC
- China is developing nuclear power, but the bottle neck of nuclear power development is the nuclear waste, ADS can safely solve this problem and provide electric power.
- ADS is under development by CAS.
- CEPC and ADS based on a lot of same technology, such as superconducting technology and so on. The CEPC construction can be motivated by the ADS technology improvement.

Parker: sustainability

Accelerators and energy are connected in all three aspects of sustainability.

Environmentally — Negative effects on the environment from the increased energy production.

Financially — Accelerator facilities may need to secure the research activities from negative effects of energy price fluctuations.

Socially — Accelerators may compete for space and energy and other resources with sustainable food production, marginally exacerbating scarcity and price volatility.

ESS electricity

Electricity	GWh	MW max power
Accelerator	119	18
Target	21	3
Cryo	44	6
Buildings	7	1
Instruments	11	1
Controls	3	0
Heat Pumps	60	8
TOTAL	265	37

100% renewable energy

Electricity only,
all heating demand with recuperated heat,
district heating as back-up

Worlds most liberalized energy market,
choose from hundreds of suppliers

Power purchase

Public procurement

Google model

Long-term purchase,
done sufficiently in advance to allow new,
dedicated production to compete

Market mechanisms and regulation
steer towards the right choice

“Sweden is blessed with a climate in which heat can be sold all year round”

Agreement
with the local district heating company Kraftringen for connection to the district heating system, purchase of surplus heat, and back-up heat supply.

5 M€
investment to connect.

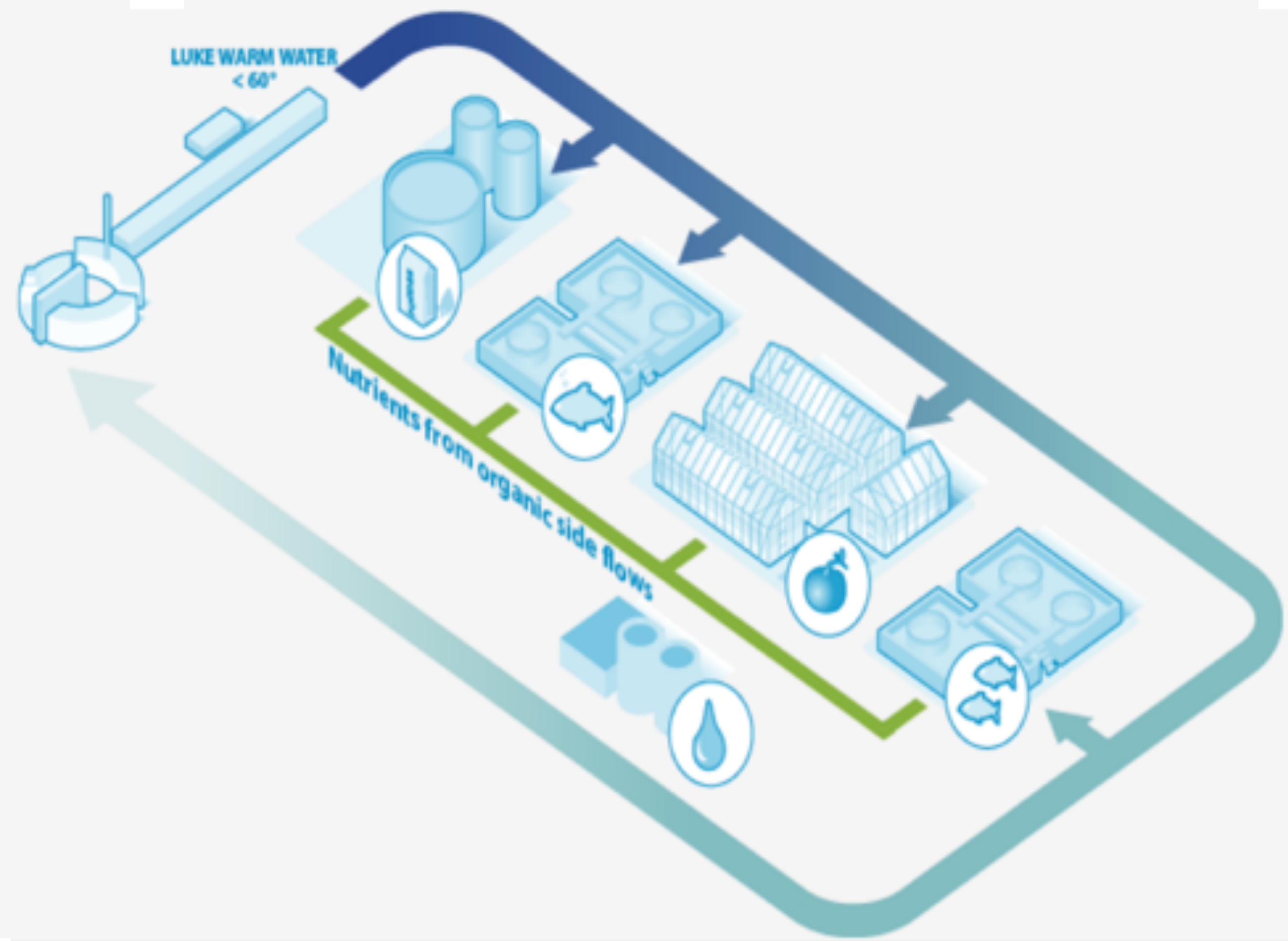
Commitment
from Kraftringen to accept all generated heat.

Full recycling
to district heating would at full operation mean a revenue of up to 5 M€ per year to ESS.

Cooling
with district heating requires 80° C heat and gives 50°C back. Heat pumps are needed for lower-temperature cooling.

Low temperatures
can be used for food production with greenhouses fish farming and fermentation with microbes.

Similar revenue to ESS,
lower costs, lower energy use, increased food security and quality, improved land and sea environment.



Parker: conclusions

An energy program is now expected.

"Responsible, Renewable, Responsible"
is neither perfect nor universal, but a benchmark
for future development and may be useful to showcase.

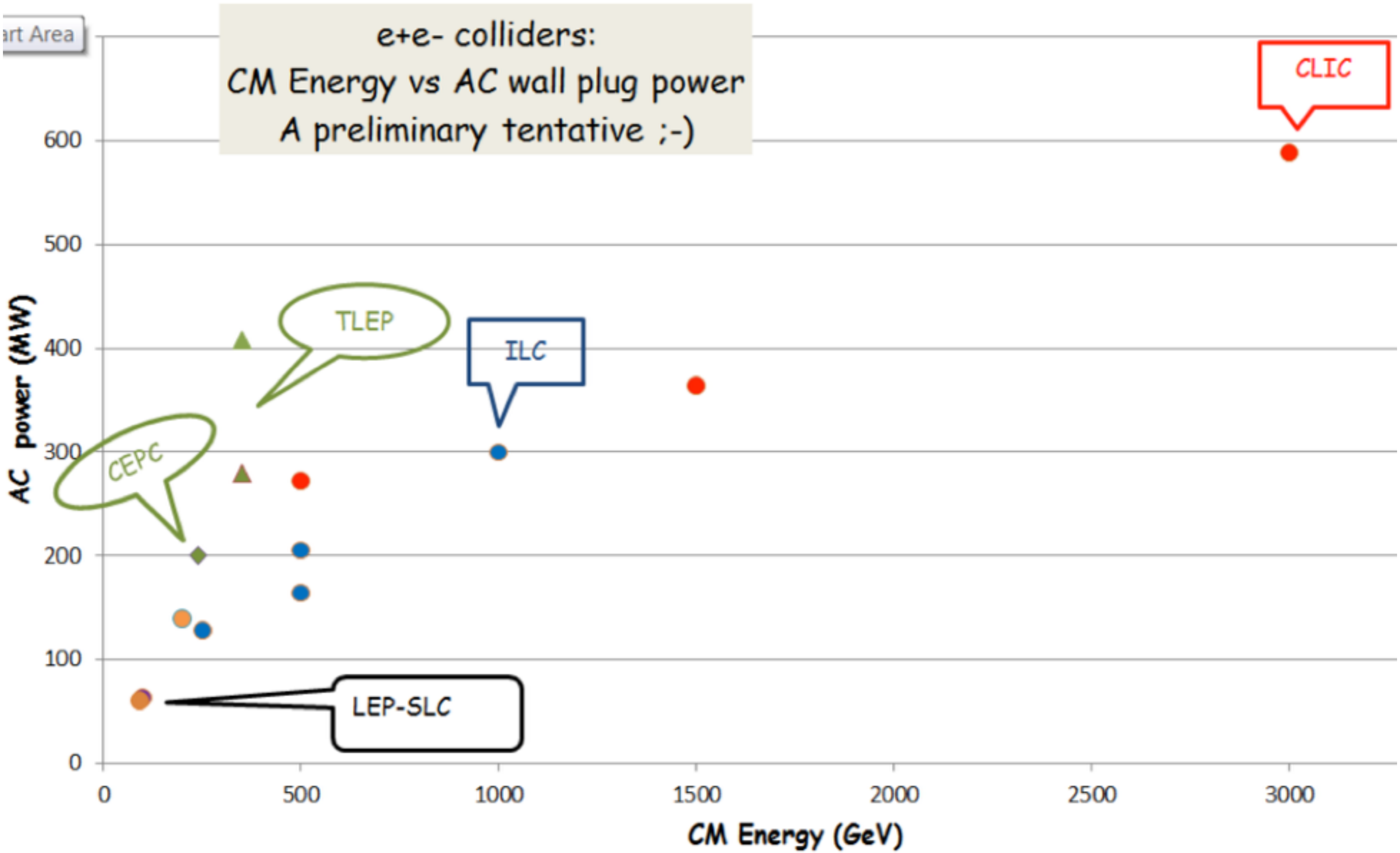
Energy efficiency must be the primary objective.
The total efficiency of accelerators is not impressive.

Major improvements
can usually only be made before the facility is built,
with the combined strength of design flexibility and buying power.

How to do heat recycling

- Don't. Efficiency – avoid creating the heat.
- 2nd law. High temperature cooling.
- Create uses of low grade heat.

Perret-Gallix: power vs CM energy



Power & energy

LHC-CERN ~ 180 MW → 1.3 TWh/year ~ 50% Geneva canton electricity consumption

FCC-ee : 354 MW @ 350 GeV (top ring and pre-injection not included)
FCC-hh : 468 MW @ 100 TeV (pre-injection NOT included (+100 MW ??) (P. Collier)

ILC: 164MW @ 500GeV - 300MW @ 1TeV (TDR)
Experiment, Computing, Buildings => 180 MW @ 500 GeV, 320 MW @ 1 TeV.
TDR takes an even larger margin: 300 MW 500 MW

ILC 500 GeV 18% of Iwate prefecture electricity consumption, Morioka (300,000)
ILC 1 TeV 32%

- 180$/MWh 2011 for industry (JP OECD 2013 report, special discount?, price volatility (2024))
- CERN (2011, 70 $/MWh), ESS (Sweden, 110 $/MWh)

Yearly electricity running cost: 500 GeV ~ 210 M$
1 TeV ~ 380 M$

"Make it global (ICFA ?)"

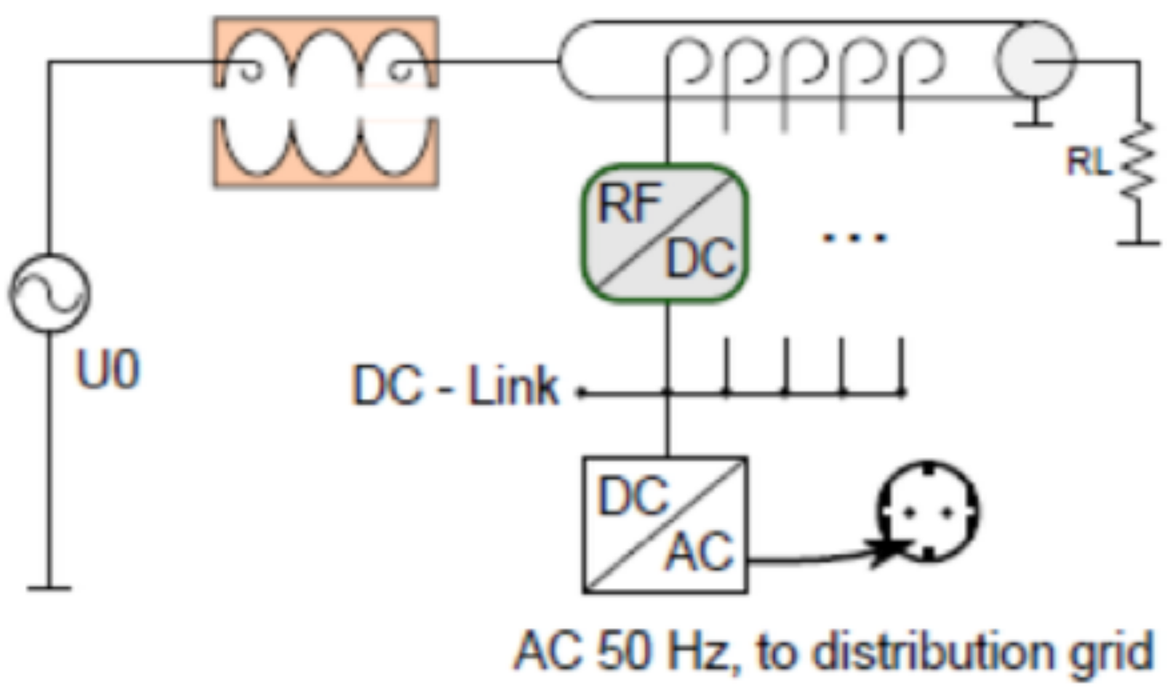
EuCARD-2: Enhanced European Coordination for Accelerator Research & Development

EnEfficient WG

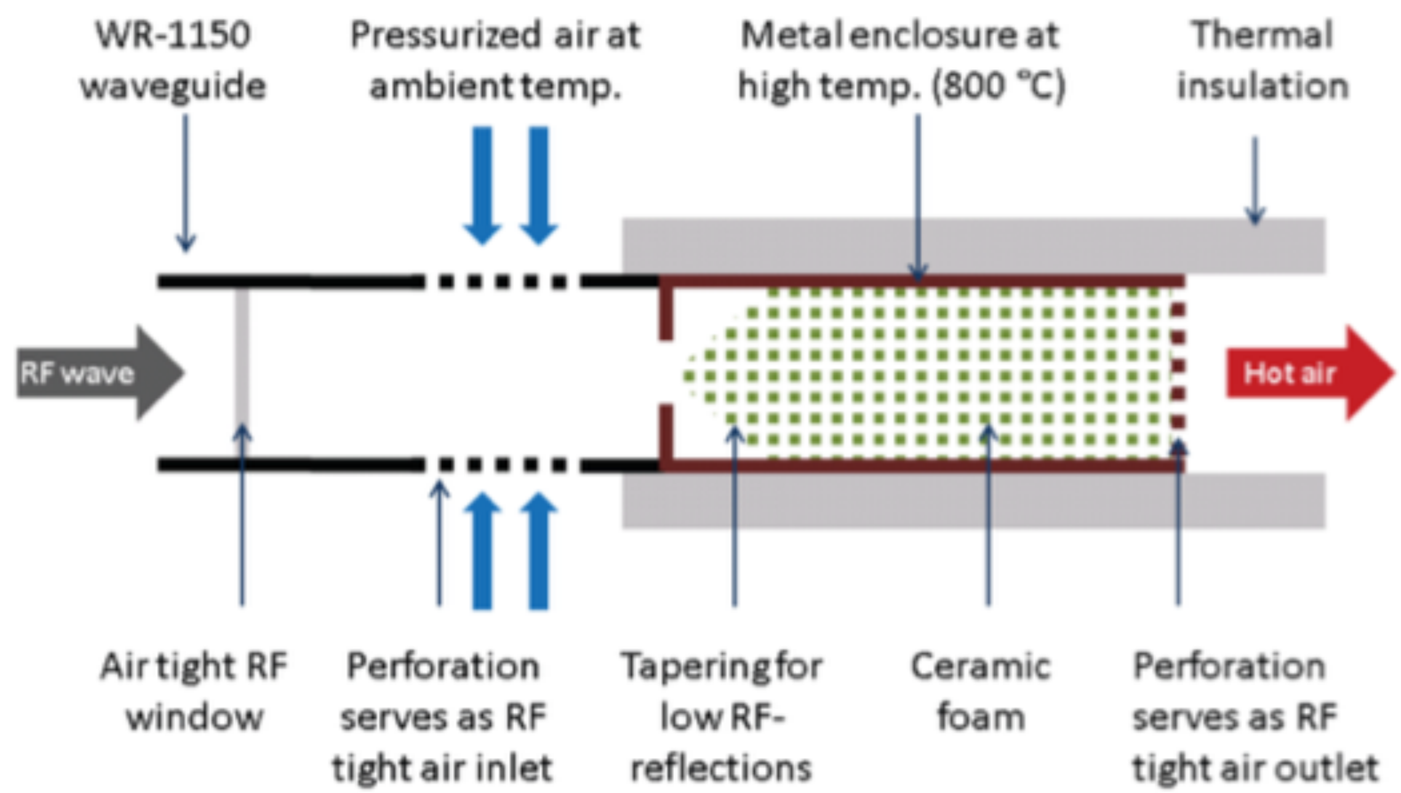
ESS, T. Parker	Energy recovery from cooling circuits
CERN, E. Jensen	Higher electronic efficiency RF power generation
KIT, M. Sanders	Short term energy storage systems
GSI, J. Stadlmann	Virtual power plant
GSI, G. Spiller	Beam transfer channels with low power consumption

Recover non-used RF power: Smart RF loads

Idea 1) – reconvert to DC power!



Idea 2) – use high-*T* loads!



LN_2 economy

The ILC cryogenics is consuming ~ 40 MW (25% of ILC AC power)

- In current design all cooling is done with LHe. LN2 as a primary coolant -> 20 MW
- LN2 cooling: HTc (MgB2) power transmission lines, NC magnets, electronics/computers,
- LN2 could be used to recycle low grade heat waste or/and high temp. beam dumps
- And produce electricity with high-pressure gas turbine (70% efficiency)

LN2 could be produced by sustainable energies

- Close to or at the ILC site (wind, solar, geothermal energy)
- Wind energy: from electricity or direct compression
- Byproducts: liquid oxygen, argon, capture CO_2, …

LN2 Energy storage

Sumimoto

First LN2 car

Perret-Gallix: conclusions

- Energy consumption is a burning hot parameter
  - Linked to many scientific, technological, financial, societal, political issues
  - Could be a no-go for some projects
  - Not a taboo or worst a technical detail: must be bluntly addressed

- Future of HEP: Saving, recovery, recycling: a must, but not enough for sustainability,
  → renewable energy
  - Follow and contribute to energy/environment civilization shift
  - Storage, a master word, needed for recycling and renewable energies.
  - E.g. LN_2 economy

- Energy R&D is core to HEP Research
  - HEP is all about energy, HEP needs energy.
  - Must structure a Global effort:
    - Build on existing initiatives: Green-ILC, EUCARD2 EnEfficient, Sustainable Science Workshop,…
    - Collaboration with Energy R&D and Industry (Japan AAA Green-ILC)
    - ICFA could take initiative: sustainable accelerator panel
  - Next global infrastructure should be seen as an "Energy Center"
  - Make HEP a bright future and bring benefit to the society

Saeki: ILC consumption & loss

ILC 500 GeV total power ~200 MW

Improve efficiency

	loss rate
Infrastructure : 50 MW	50 % : 25 MW
RF System : 70 MW	50 % : 35 MW
Cryogenics : 70 MW	90 % : 60 MW
Beam Dump : 10 MW	100 % : 10 MW
200 MW	~ 130 MW

Obligation to Us

Increase recovery

Green-ILC meeting topics:

May & July 2014

1) Collector Potential Depression (CPI) Klystron (30 min.)
   by Toshiba Electron Tubes & Devices Co. Ltd.

2) Power Saving of Large-Scaled Helium Compressor (30 min.)
   by Mayekawa Manufacturing Company.

3) Examples of New Energy Power Plants (20 min.)
   by RIKEN.

4) Solar Power Plant (40 min.)
   by Japan Photovoltaic Energy Association

5) Proposal of Biomass Power Plant for ILC (20 min.)
   by Kabuki Construction Co. Ltd.

1) Energy Recovery at Beam Dump at ILC (20 min.)
   by J. Fujimoto (KEK).

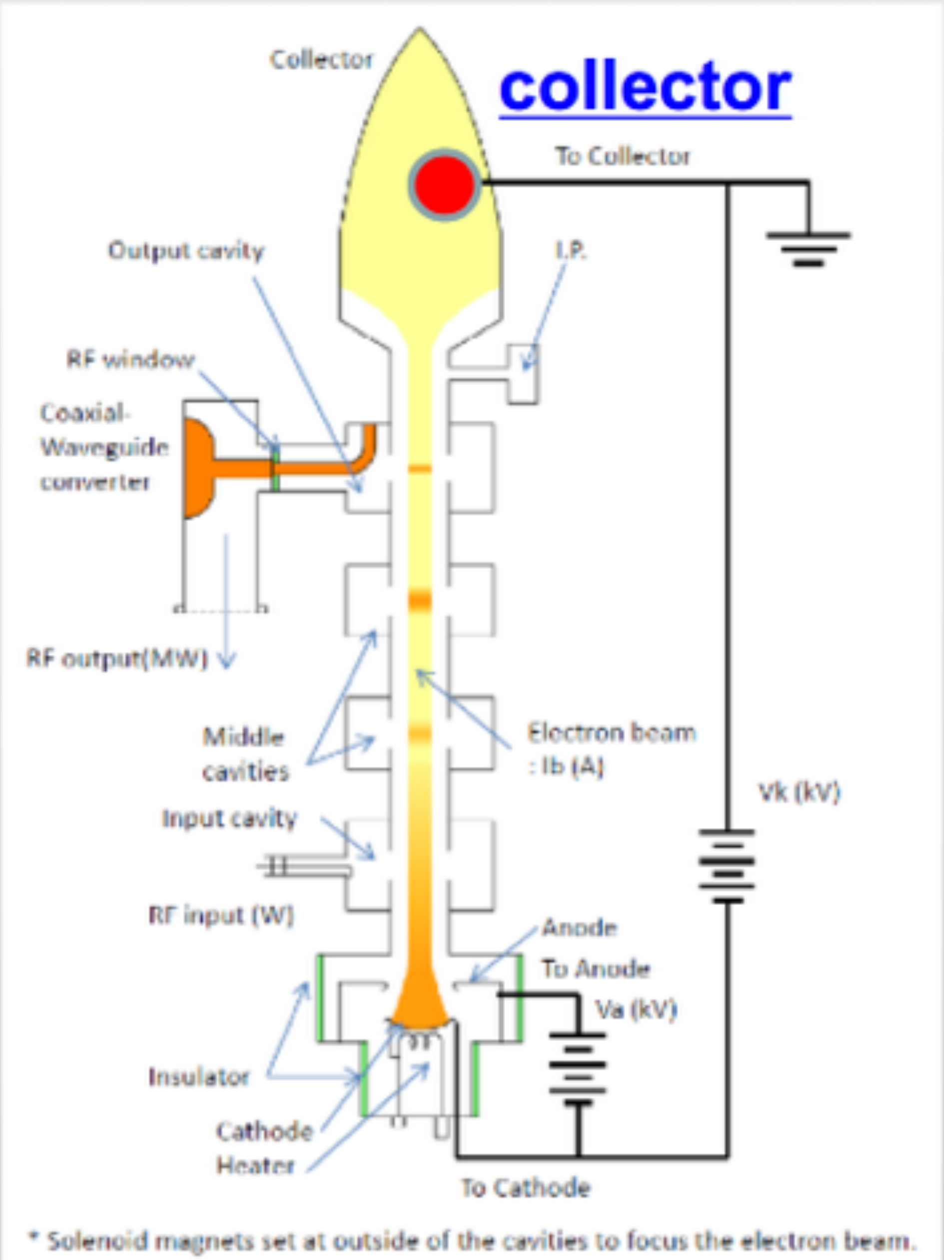
2) Tests of Collector Potential Depression (CPD) Klystron (30 min.)
   by K. Watanabe (KEK).

3) Drag Reduction (DR) Additive for Cooling Water (30 min.)
   by Shin Nippon Air Technologies Co. Ltd.

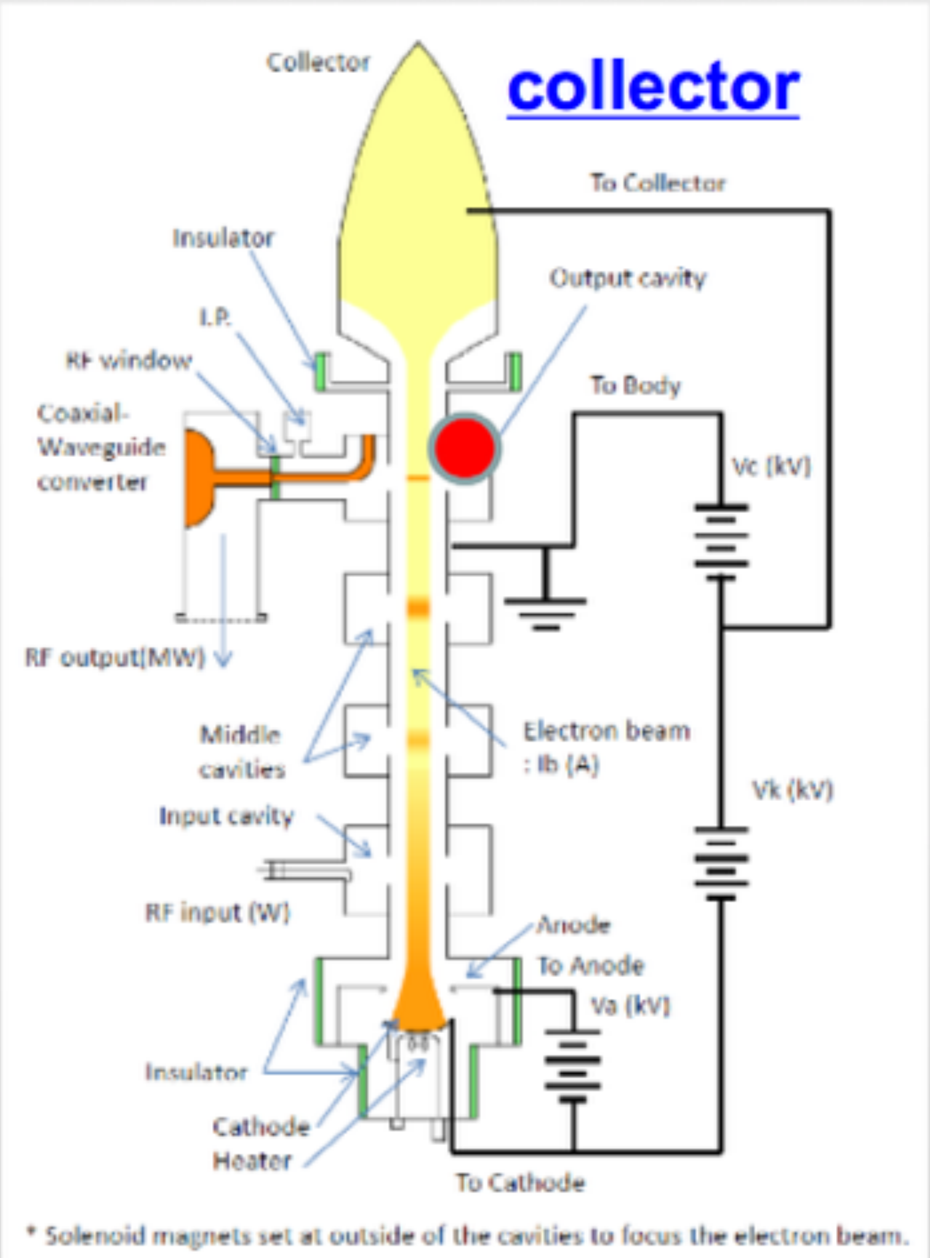
4) Examples of New Energy Power Plants (30 min.)
   by RIKEN.

Collector potential depression: 80% efficiency?

Conventional



Schematic diagram of CPD

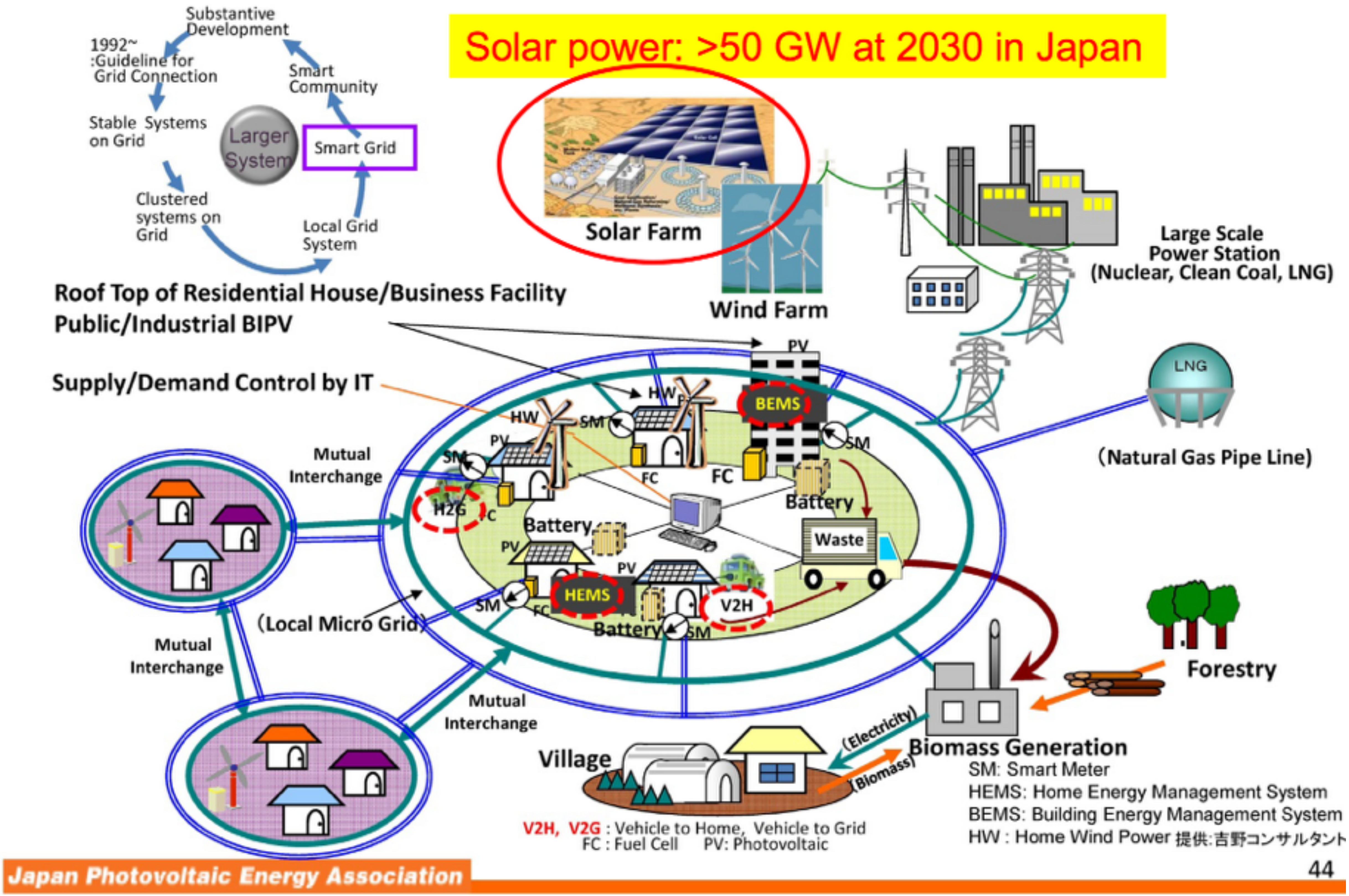


Co-generation system at RIKEN

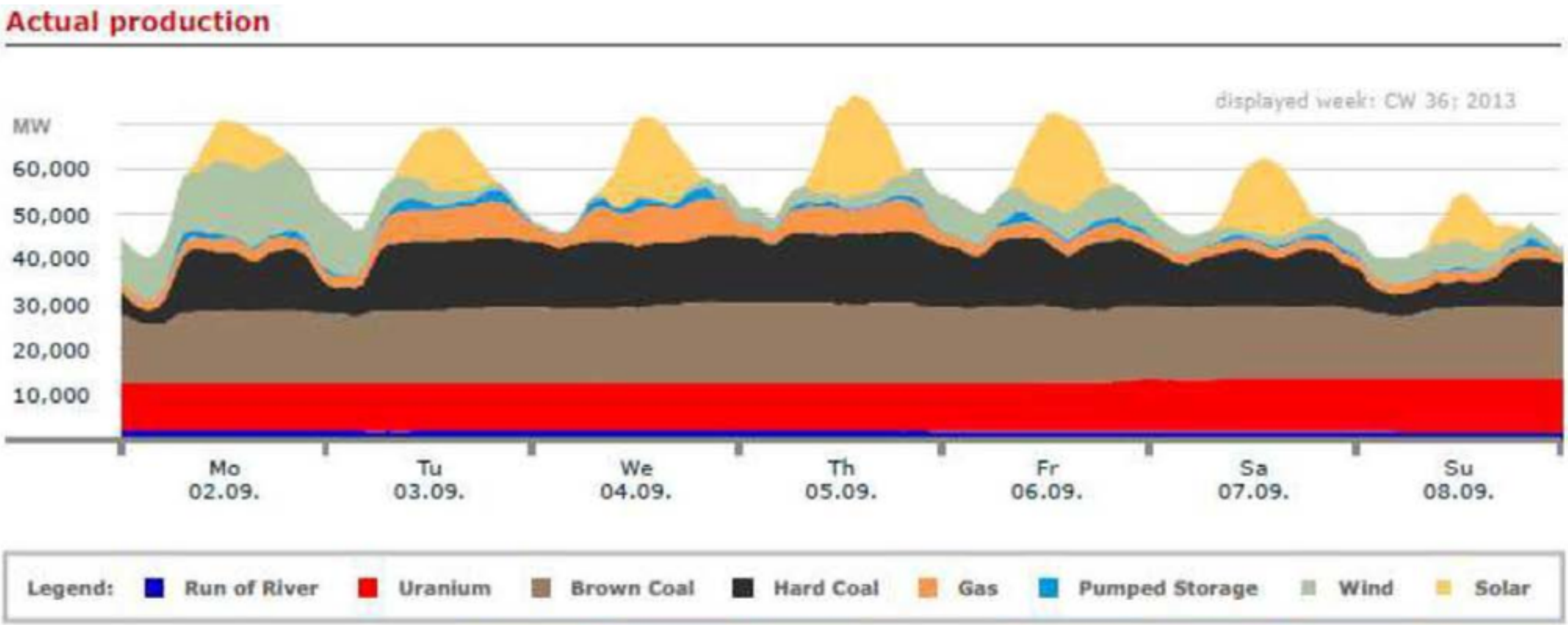
- 6.5 MW + 2720 USRT
- 1Hz (20msec) power switch for blackout.
- Efficiency：68%, as of June 2010.

- G：7MVA. 6.6kV. 50Hz.
- T :1100℃/480℃. 14000rpm. 6.6MW /12℃.
- B :480℃/160℃. 1.6MPa(210℃)12.5t/h
- C :400 USRT x 5 + 360 USRT x 2,   7℃ at outlet (1 USRT=3.52kW.)

Smart grid - local micro grid



One week of German power production



	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
min. power (GW)	1.5	10.3	12.7	3.2	2	0	0.1	0
max. power (GW)	2	11.9	17.8	16	8.7	2.8	17	22
weekly energy (TWh)	0.3	1.8	2.7	2	0.7	0.1	0.9	0.8

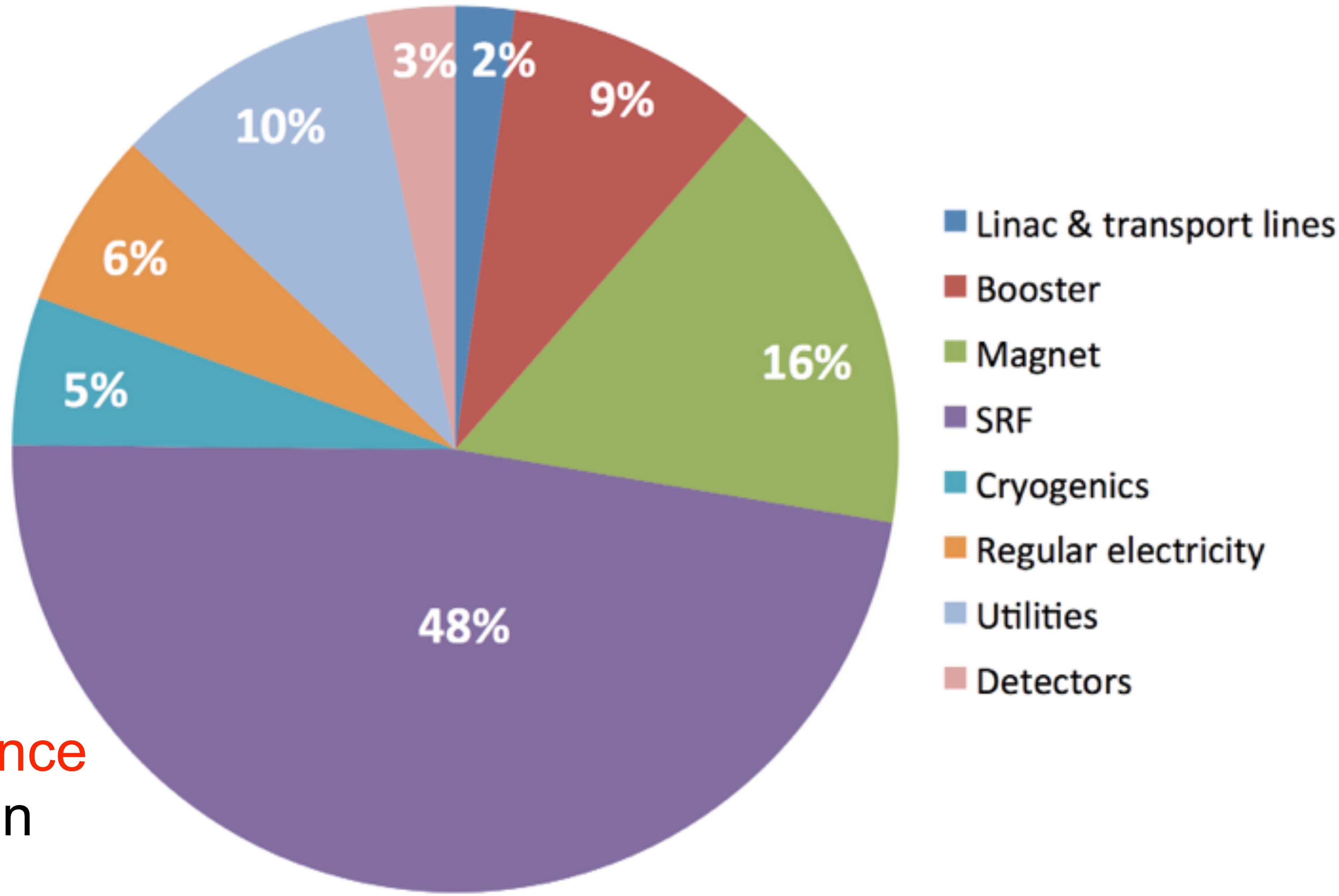
Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform

Saeki: conclusions

- The 1st meeting for the Green-ILC WG of AAA was held on 25th February 2014 to launch the Green-ILC-AAA activity.
- The series of Green-ILC-AAA WG meetings were held since then, and various realistic technologies of energy-saving for ILC were proposed and discussed by industries and scientists in the meetings.
- The energy-saving technologies discussed in the Green-ILC-AAA meetings are ranging from the components, sub-system, ILC-system, and ILC-city.
- Proposed items for Green-ILC energy-saving technologies will be summarized and written in the report under the framework of AAA in the year of 2015.

Qin & Chou: CEPC power consumption

Total site power of ~300 MW is dominated by SRF



A larger circumference reduces synchrotron radiation power

$$L_{\text{limit}} = 0.4565 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1} \frac{\rho(\text{km}) P_{\text{SR}}(100\text{MW}) \sqrt{\delta_{\text{BS}}(0.1\%)}}{(E/100\text{GeV})^{4.5} \sqrt{\varepsilon_y(\text{nm})}}$$

Chou: AC to beam efficiency

Table 1-1: Comparison of wall-plug efficiency of various accelerators.

Accelerator	Beam	Beam energy (GeV)	Beam power (MW)	Efficiency AC to beam	Note on AC power
PSI Cyclotron	H+	0.59	1.3	0.18	RF + magnets
SNS Linac	H^-	0.92	1.0	0.07	RF + cryo + cooling
TESLA (23.4 MV/m)	e^+/e^-	250 × 2	23	0.24	RF + cryo + cooling
ILC (31.5 MV/m)	e^+/e^-	250 × 2	21	0.16	RF + cryo + cooling
CLIC	e^+/e^-	1500 × 2	29.4	0.09	RF + cooling
LPA	e^+/e^-	500 × 2	8.4	0.10	Laser + plasma

Yesterday Perret-Gallix's talk: ILC wall plug efficiency: 9.6%

Conclusions

1) The green accelerator challenge/opportunity is with us to stay
   - Globalise a EuCARD2-style initiative - through ICFA?

2) There is no complete consensus on what accelerator-specific things to do. But clearly we need to work on:
   - Wall-plug-to-beam efficiency of RF power sources
   - "Cryogenic system" (in the broadest sense) efficiencies

3) We also need to follow & help to develop generic (non-accelerator-specific) green engineering
   - National labs offer safe environments for higher risk innovation

4) A larger Circular Collider circumference:
   - is greener for CC-ee
   - reduces annual operating costs
   - enhances CC-pp upgradability & reduces the SC dipole B-field