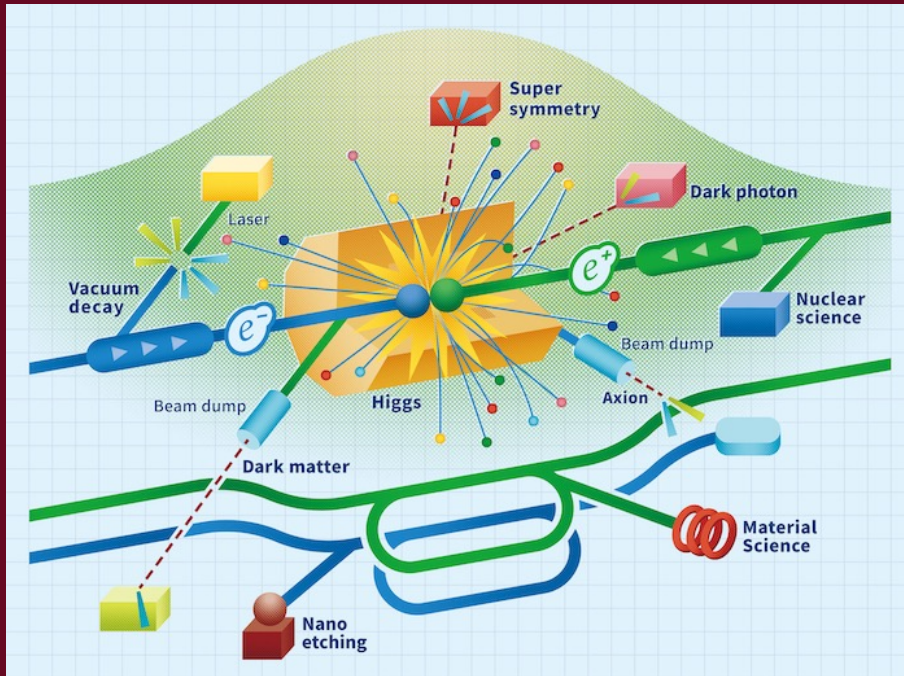


# International Development Team



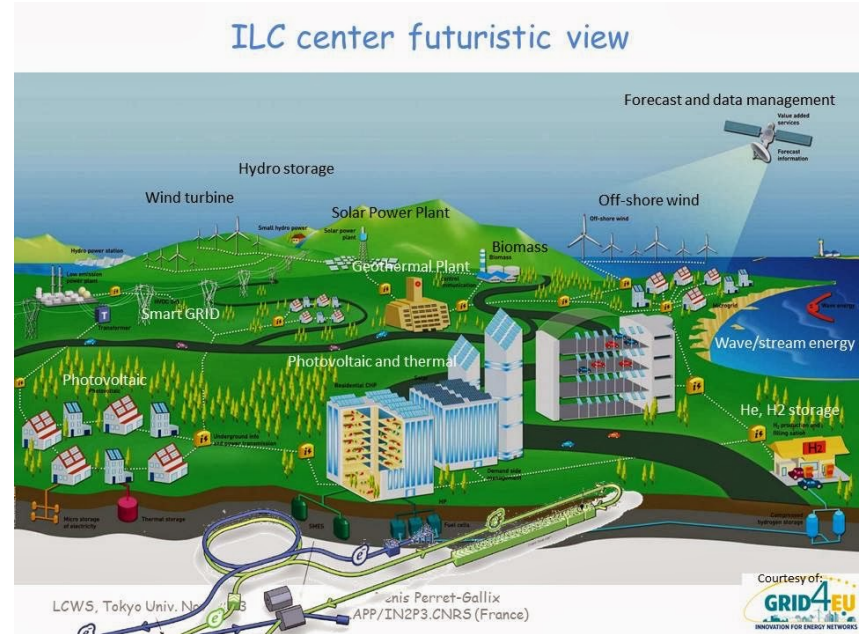
**ILCX2021** ILC Workshop  
on Potential Experiments

Sustainability Issues  
Benno List, DESY  
Green ILC, ILCX 2021  
19.10.2021

- Luminosity closely related to electric power

$$\mathcal{L} = \frac{\eta P_{AC}}{E_{CM}} \cdot \frac{N_e}{4\pi \sigma_x^* \sigma_y^*} H_D$$

- HEP accelerators require large amounts of electricity:
  - ILC250: 110MW
  - ILC 1 TeV: 300MW -> significant fraction (~30%) of output of a (nuclear) power plant block
- Energy efficiency has been at the heart of the ILC concept -> superconducting RF to increase efficiency
- To increase sustainability: use “green” energy from renewable sources
- Beam power of linear accelerator can be changed quickly – can adapt to power availability!



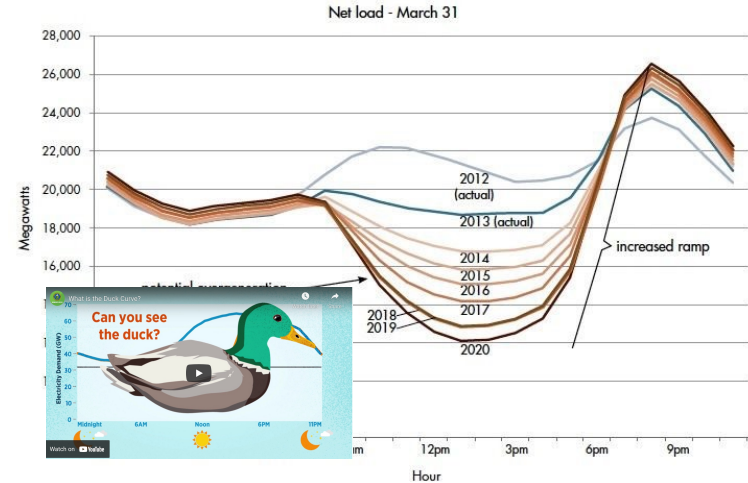
<https://green-ilc.in2p3.fr/home/>

- Different approaches to reduce impact of large electric power consumption
  - Reduce power (by higher efficiency)
  - Re-use waste energy (heat)
  - Modulate power according to availability (price)
  - Use regenerative power
- Regenerative energy sources (esp. solar, wind) vary seasonally and daily
- Public electricity demand also varies
  - > daily “duck curve”, seasonal variation
- Use of regenerative energy sources (RES) should be combined with power modulation
- -> Study power consumption in different operating states of ILC
- Two ways to modulate power usage
  - Change performance
  - Buffer energy



Figure 2-3: Day-Ahead auction results at EPEXSPOT for trading area France and year 2017 (orange: price peakload, black: price baseload)?

<https://edms.cern.ch/document/2065162/1>



<https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy>

- CLIC Study: consider 5 operating modes:
  - Off (shutdown)
  - Standby and intervention – scheduler or unscheduled
  - Low power running (50% lumi)
  - Full operation
- Study assumes target of 130days of full operation equivalent running
- Considers impact of various running strategies on energy costs

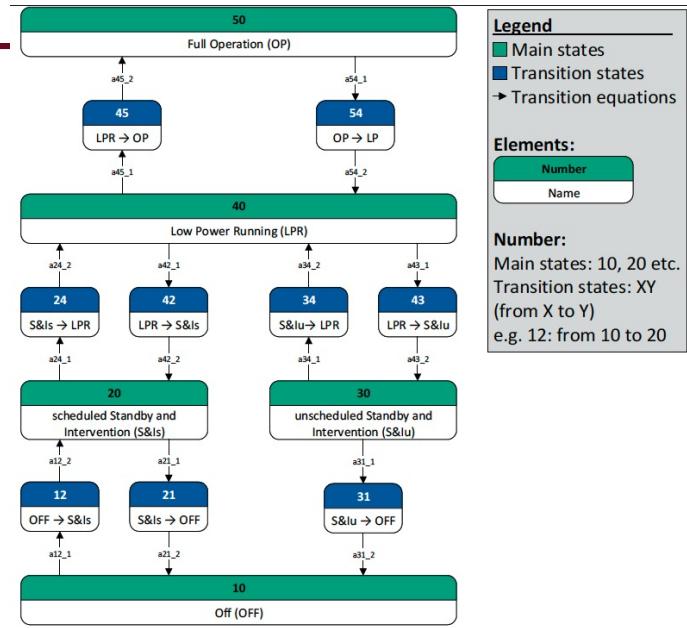


Figure 1-1: Schematic representation of the finite state machine

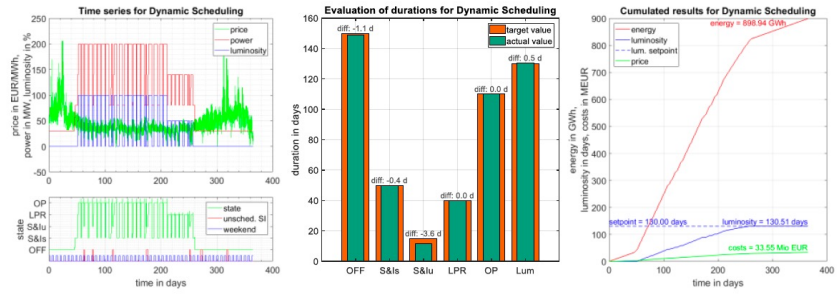


Figure 1-18: Example plots of a simulation run (left: time series, middle: bar graph with durations, right: cumulated times)

Table 1-2: Parameters of main states

Main states	power	min. duration	max. duration	occurrence s per year	duration per year
	$P$	$T_{min}$	$T_{max}$	$N_{max}$	$T_{sum}$
10 Off (OFF)	30 MW	1 months	4 month	1-4 times	$T_{OFF}$
20 scheduled Standby and Intervention (S&Is)	80 MW	1 day	4 days	40 times	$T_{S&Is}$
30 Unscheduled Standby and Intervention (S&Iu)	80 MW	1 day	4 days	approx. 5 times	$T_{S&Iu}$
40 Low Power Running (LPR) lum = 50% (luminosity)	140 MW	Together four hours	Together six days	-	$T_{LPR}$
50 Full Operation (OP) lum = 100% (luminosity)	200 MW			-	$T_{OP}$

- Full operation
- Reduced luminosity: 50%
  - Reduce repetition rate to 2.5 Hz for best ML efficiency
  - First estimate: **saves 20 MW** (12 – 13MW RF power, 3-5MW Cryo, 2.5 MW CFS) in ML
- Standby (maintenance mode)
  - No beam, no luminosity, RF off
  - Cryomodules cold
  - Water cooling, HVAC on
  - Magnets: on or off?
  - Simplest assumption: saves another 20MW
- Shutdown
  - Cryomodules stay cold
  - Magnets off
  - Water cooling, HVAC minimal
- Off (including power outage)
  - Cryomodules warm

Considerations on reduced luminosity mode:

- Only a fraction (about 40MW) of total power consumption scales with beam intensity / luminosity
- Overall efficiency L/P always gets worse for low power operation
- Running at low power during times of expensive electricity extends overall run time – generally costs money  
-> may be interesting if compensated by power company

	500 TDR	250-A	250-A' w/R&D	250 2.5 Hz	250 2.5 Hz w/R&D	Standby (RF off)
Rep-Rate / Hz	5	5	5	2.5	2.5	0
Bunches / Pulse	1312	1312	1312	1312	1312	0
Lumi / 10 <sup>34</sup>	1.8	1.35	1.35	0.68	0.68	0
Gradient / MV/m	31.5	31.5	35	31.5	35	
Q <sub>0</sub> /1E10	1.0	1.0	1.6	1.0	1.6	
ML E-gain / GeV	470	220	220	220	220	
ML Power / MW	107.1	50.1	49.3	30.1	29.1	10.0
e- Src / MW	4.9	4.9	4.9	5.6	4.9	5.6
e+ Src / MW	9.3	9.3	9.3	10.2	9.3	10.2
DR / MW	14.2	14.2	14.2	14.2	14.2	14.2
RTML / MW	10.4	10.4	10.4	10.4	10.4	10.4
BDS / MW	12.4	9.3	9.3	9.3	9.3	9.3
Dumps / MW	1.2	1.2	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7	2.7	2.7
Gen. Margin/MW	5.1	3.3	3.2	2.7	2.6	2.1
<b>Total</b>	<b>173</b>	<b>111</b>	<b>110</b>	<b>91</b>	<b>90</b>	<b>70</b>

Based on ILC-CR-0018

Simple estimate  
Based on scaling  
RF and dynamic part  
of cryo power

Not updated



- Damping Rings consume 14MW (13%) of total power
- At 2.5Hz operation, beams circulate for 400ms instead of 200ms  
-> longer damping time sufficient?
- Can wiggler fields be reduced and RF power saved?
- Damping rings consume
  - 7.4MW RF power
  - 1.5MW cryo power
  - How much could be saved at 2.5Hz operation?

	500 TDR	250-A	250-A' w/R&D	250-A Lx2
Rep-Rate / Hz	5	5	5	5
Bunches / Pulse	1312	1312	1312	2625
Lumi / 10 <sup>34</sup>	1.8	1.35	1.35	2.7
Gradient / MV/m	31.5	31.5	35	31.5
Q <sub>0</sub> /1E10	1.0	1.0	1.6	1.0
ML E-gain / GeV	470	220	220	220
ML Power / MW	107.1	50.1	49.3	53.5
e- Src / MW	4.9	4.9	4.9	5.6
e+ Src / MW	9.3	9.3	9.3	10.2
<b>DR / MW</b>	<b>14.2</b>	<b>14.2</b>	<b>14.2</b>	<b>22.2</b>
RTML / MW	10.4	10.4	10.4	13.3
BDS / MW	12.4	9.3	9.3	9.3
Dumps / MW	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7
Gen. Margin/MW	5.1	3.3	3.2	4.0
<b>Total</b>	<b>173</b>	<b>111</b>	<b>110</b>	<b>138</b>

From ILC-CR-0018

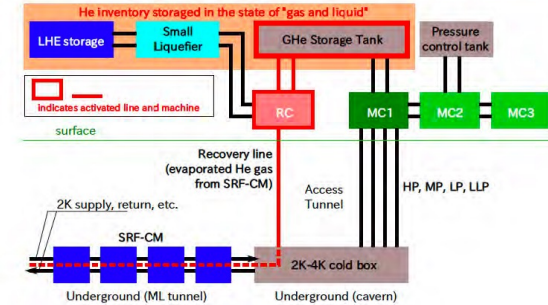
- Buffer energy to adapt power demand to power availability – use more RES
- Many techniques available:
  - Batteries
  - Flywheel
  - Pumped water reservoirs
- Unspecific technologies can be employed by ILC lab or by power company – limited public benefit if done by ILC (except PR)?
- Look for accelerator specific energy buffers!
- Thermal buffers:
  - Liquid helium
  - Cold cooling water
- -> Cool now, use later





- ILC-250 uses 13.1 – 15.4MW electricity for cryo power (13.1 “R&D success”)
- Storage tanks for LHe and GHe with large capacities are available
- Cryo plants are designed for 40% overcapacity
- Can the 4.5K stage be shut down during day times with large electricity demand?
- Define three operating stages
  - Nominal operation (“100%”) – 13 - 15 MW
  - Overproduction (140%) – 18 – 21 MW
  - Power saving (xx%) - maybe 3MW???
- Run in power saving mode during day times with highest electricity demand, replenish storage during times with surplus energy

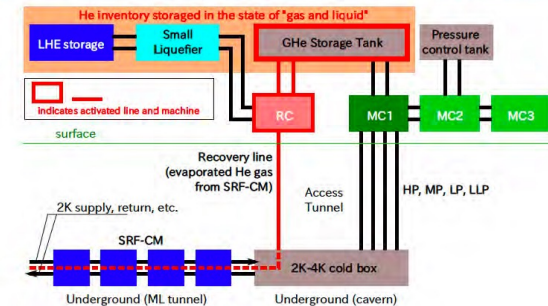
## Block Diagram (during Power Failure Operation)



- RC is operated by using Natural gas/oil generator.
- Other equipment keeps halting condition

T. Okamura, H. Nakai, A. Yamamoto (KEK) ML Cryogenics 2017/3/13 11 / 39

## Block Diagram (during Power Failure Operation)



- RC is operated by using Natural gas/oil generator.
- Other equipment keeps halting condition

T. Okamura, H. Nakai, A. Yamamoto (KEK) ML Cryogenics 2017/3/13 11 / 39

Thanks to D. Delikaris for explanations and insight!

- IAEA Conference on accelerators for research and sustainable development
- Vienna, May 23-27, 2022
- Submitted an abstract for ILC and CLIC: “Sustainability studies for linear colliders”
- Intent: Provide an overview over measures to increase sustainability of ILC and CLIC
  - Overall design
  - Energy saving components
  - Renewable energy sources
  - Waste heat usage
- Workshop “Energy for sustainable science at research infrastructures”
  - Grenoble, France (ESRF), Mar 17/18, 2022

#Accelerators2022

International Conference on Accelerators for Research and Sustainable Development: from good practices towards socioeconomic impact

23-27 May 2022  
IAEA Headquarters  
Europe/Vienna time zone

**1 NOVEMBER 2021 IS THE NEW DEADLINE FOR SUBMISSION OF SYNOPSIS AND FORMS A, B, C**

Overview	
<b>Purpose and Objectives</b>	<b>Purpose and Objectives</b>
Expected Outcomes	
Target Audience	
Participation and Registration	
Themes, Topics and Structure	
Submit new Synopsis	
Submission of Full Papers	
Expenditures and Grants	
Venue, Accommodation and Visas	
IAEA Meeting Webpage	
<b>Contact</b>	
✉ <a href="mailto:AccConf2022@iaea.org">AccConf2022@iaea.org</a>	

The Conference aims primarily to present an international stage for discussing accelerator applications in research and industry, foster exchange of information on best practices in accelerator facility utilization and management, and to provide a showcase how achievements and experience attained with accelerator technologies contribute to a sustainable development. All types of accelerators will be considered: from low-energy ion-beam electrostatic accelerators to cyclotrons, from compact accelerator-based neutron sources to large-scale spallation facilities, from electron-based irradiation facilities to synchrotron light sources, and many others.

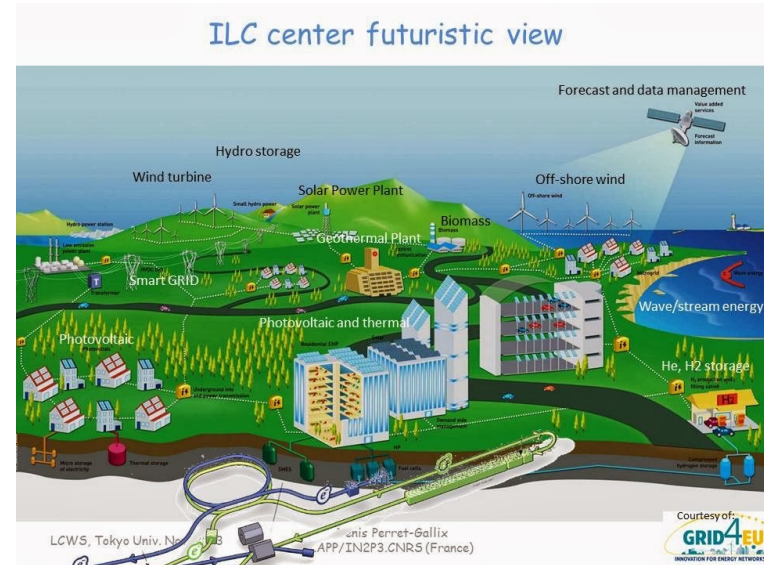
Special emphasis will also be given in accelerator applications of large societal impact such as human health, environmental monitoring, cultural heritage, food quality, energy sector, forensics, nuclear security, and others promoting economic development. The Conference will provide a unique opportunity to achieve the following specific objectives:

- To disseminate:
  - New knowledge and technologies developed through accelerator-based research and applications in a wide spectrum of scientific areas.
  - Best practices in establishing new accelerator facilities, and ensuring their effective management and sustainability
- To review:
  - Key developments in particle accelerator technologies, established and emerging ones, and their role in enhancing innovations
  - National, regional and global initiatives for implementing proven accelerator applications that lead to socio-economic benefits and strengthen capacity building in Member States; and
- To serve:
  - As a composite platform through which academia and industry can foster new initiatives for ensuring the success of accelerator applications in addressing the emerging challenges in multiple disciplines.
  - As a bridge to enhance existing and establish new collaborations among scientists and institutions from Member States aiming at benefiting from accelerator technologies to face challenges in a series of problems of modern society.

Indico Powered by Indico v2.3.5 [Help](#)

<https://conferences.iaea.org/event/264/>

- In addition to saving energy (better klystrons, permanent magnets) and reusing waste heat (green houses etc), consider **modulating power consumption** for better use of regenerative energy sources
- Look for accelerator specific solutions
- Adapt running strategy to RES availability
  - Scheduling
  - Special run modes
- Buffer energy
  - Cryo plants
  - Cooling water?



<https://green-ilc.in2p3.fr/home/>