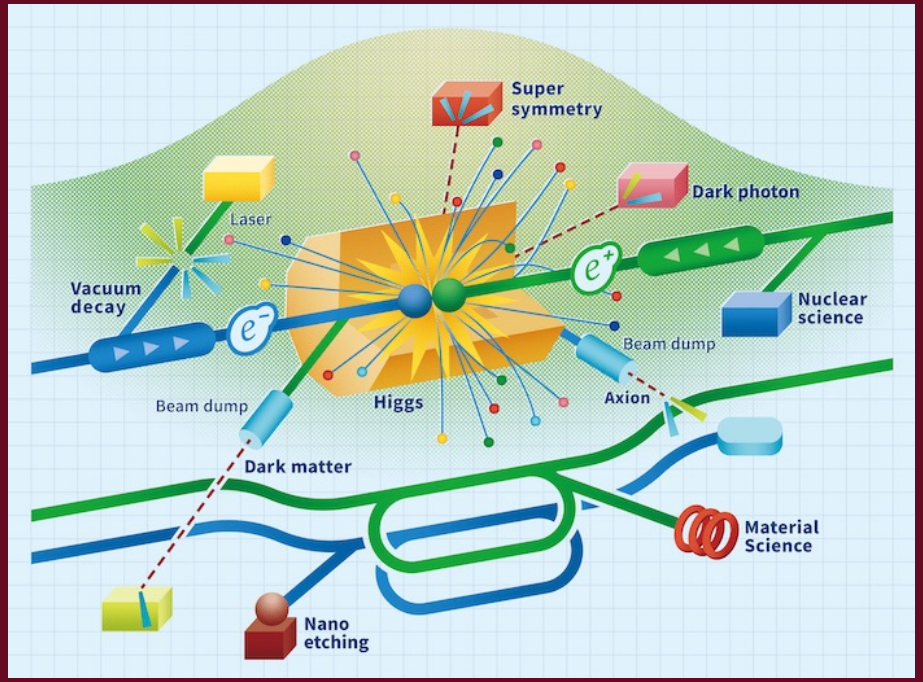
International Development Team



ILCX2021 ILC Workshop on Potential Experiments

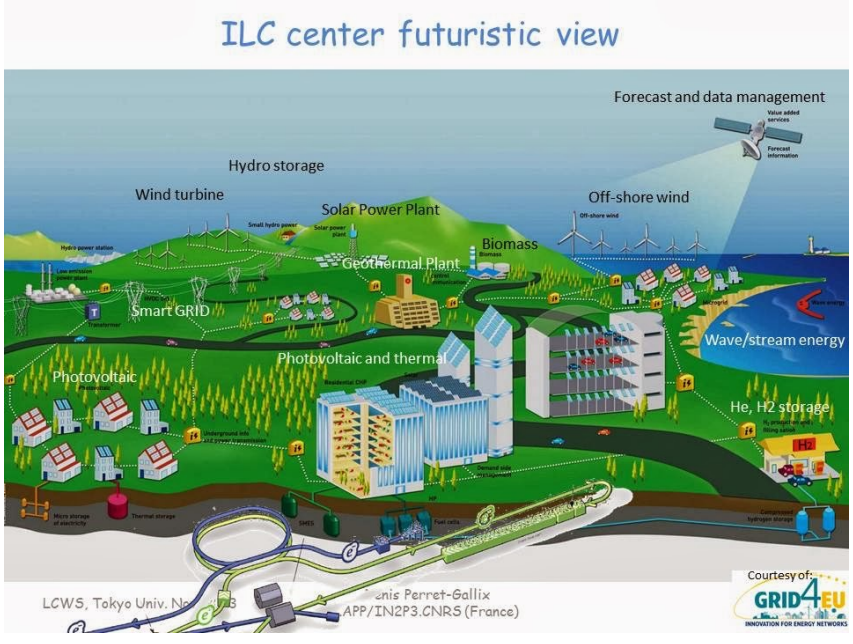
Sustainability Issues
Benno List, DESY
Green ILC, ILCX 2021
19.10.2021

Introduction

- Luminosity closely related to electric power

$$\mathcal{L} = \frac{\eta\ P_{\mathrm{AC}}}{E_{\mathrm{CM}}} \cdot \frac{N_{\mathrm{e}}}{4\pi\ \sigma_{\mathrm{x}}^{*}\sigma_{\mathrm{y}}^{*}} H_{\mathrm{D}}$$

- 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/

Approaches to increase sustainability

- 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

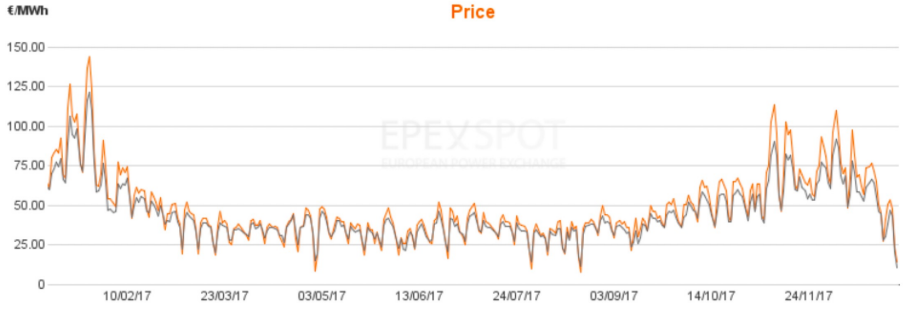
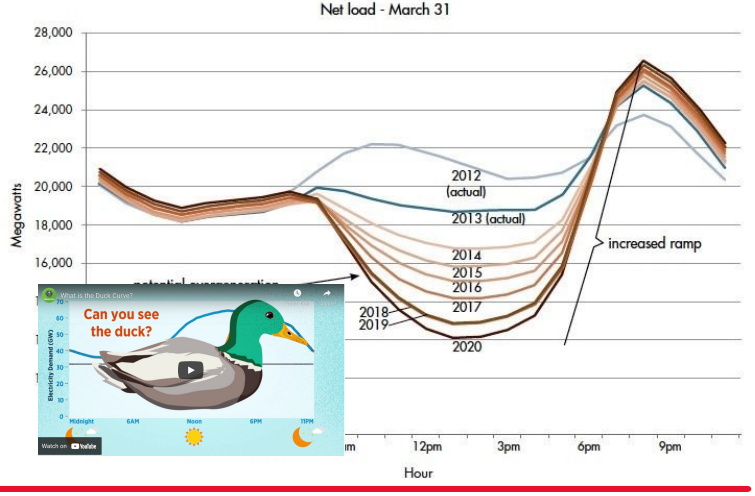


Figure 2-3: Day-Ahead auction results at EPEXSPOT for trading area France and year 2017 (orange: price peakload, black: price baseload)[7]

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



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

Operating Modes

- 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

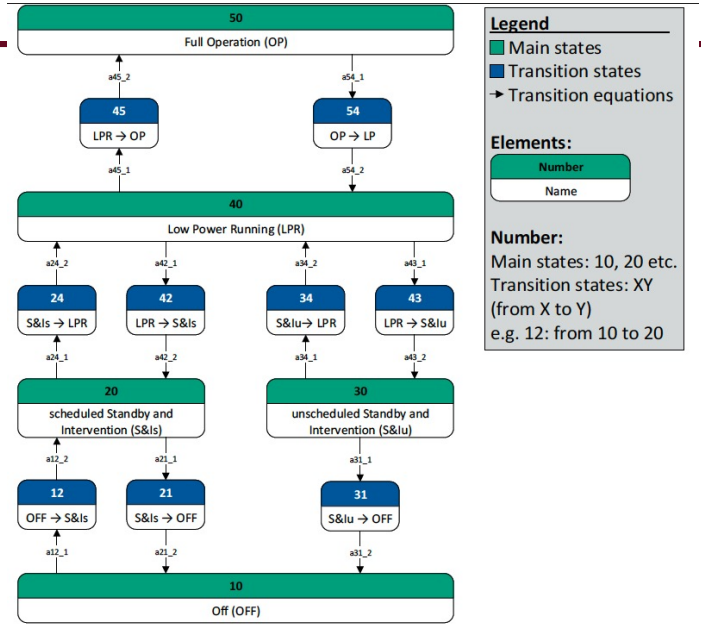


Figure 1-1: Schematic representation of the finite state machine

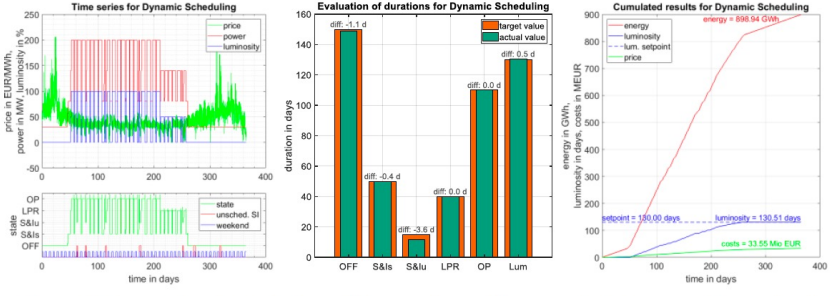


Figure 1-18: Example plots of a simulation run (left: time series, middle: bar graph with durations, right: cumulated times)

Table 1-2: Parameters of main states

Main states	power P	min. duration T_{min}	max. duration T_{max}	occurrences per year N_{max}	duration per year 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}

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

Possible ILC operating modes to consider

- 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 – generaly costs money
  -> may be interesting if compensated by power company

A very first estimate for 2.5Hz operation

	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^{34}	1.8	1.35	1.35	0.68	0.68	0
Gradient / MV/m	31.5	31.5	35	31.5	35	
Q_0/1E10	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
Total	**173**	**111**	**110**	**91**	**90**	**70**

Based on ILC-CR-0018

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

Not updated

Reduced Damping Ring Operation – needs study

- 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^{34}	1.8	1.35	1.35	2.7
Gradient / MV/m	31.5	31.5	35	31.5
Q_0/1E10	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
DR / MW	14.2	14.2	14.2	22.2
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
Total	**173**	**111**	**110**	**138**

From ILC-CR-0018

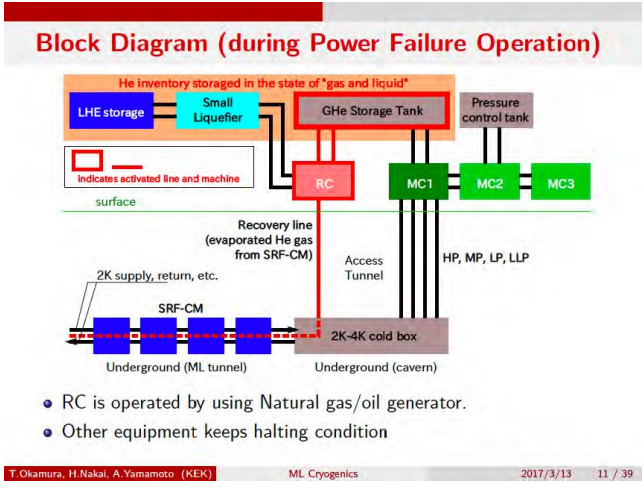
Energy Buffering

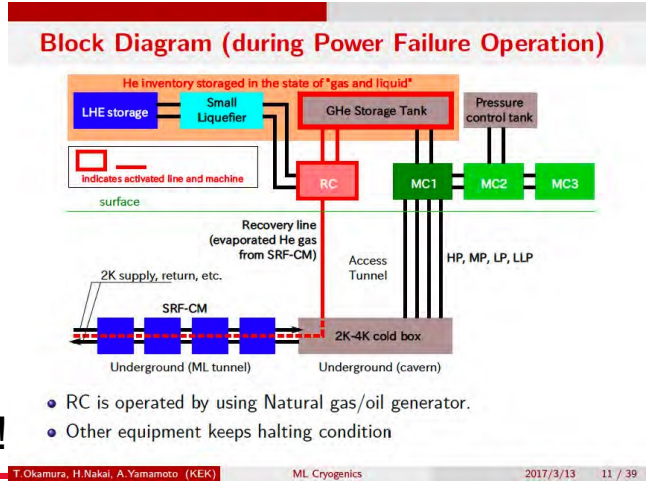
- Buffer energy to adapt power demand to power availability – use more RES
- Many techniques available:
  - Batteries
  - Flywheel
  - Pumped water reservoirs
- Unspecific technologies can be employed by ILC lab or by power company
  – limited public benefit if done by ILC (except PR)?
- Look for accelerator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

Von Nationaal Archief (flickr.com) - flickr.com, Copyrighted free use, https://commons.wikimedia.org/w/index.php?curid=11292628

Modulate Cryoplants?

- 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





Thanks to D. Delikaris for explanations and insight!

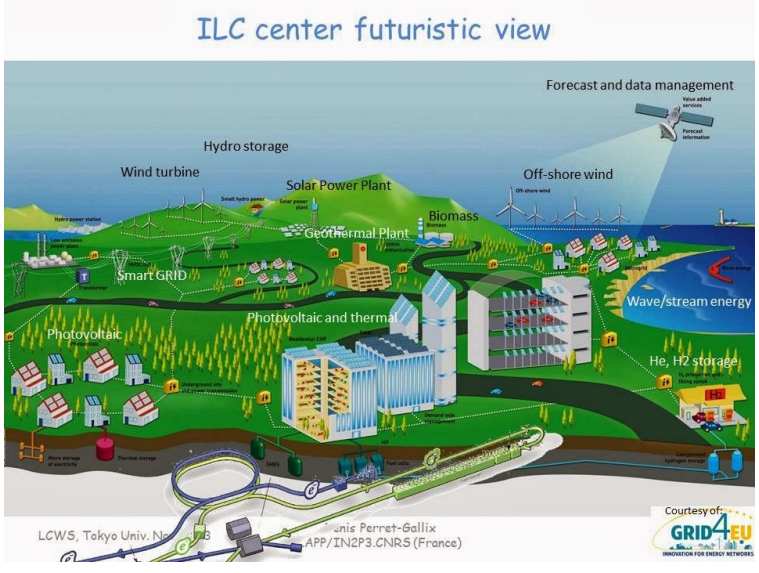
Upcoming Conference: IAEA, ESSRI Workshop

- 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

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

Summary

- In addition to saving energy (better klystrons, permanent magnets) and reusing wast 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?



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